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Jaws S3 98 Conference

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Tom Minnich

per phone call with J. Camp 10/22/98

Authorized Signature/Date

AFRL/FSD
2241 Avionic Circle
Wright-Patterson AFB, OH 45433-7318

John Camp

Print or Type Name

937 255-2164 3562

Telephone Number

JAWS S3 98 Conference Volume 2
Table of Contents

Tuesday, 16 June 1998

Dr. Patricia Sanders
Director, Test, Systems Engineering and Evaluation
Office of the Under Secretary of Defense (Acquisition and Technology)
Keynote Address
The 4th Joint Avionics, Weapons, and Systems
Support, Software, and Simulation (JAWS S3) Symposium and Exhibition
June 16, 1998

Thank you for that warm introduction. (Bill Collier, Chairman) And thank you for the invitation to speak here today.

I am particularly struck by your theme: "Meeting the technology needs of the warfighter in the year 2000 and beyond" because clearly this is the mission of my own organization. And looking to how we meet future warfighting needs with technology is certainly critical for us.

Environment

You know, meetings such as this provide us an opportunity to look to the future and I want to do that with you. Charles Kettering said we should all be concerned about the future because we will have to spend the rest of our lives there. What the future has in stock for us will depend largely on what we place in stock for the future. The worst thing about the future is that it gets here faster than it used to.

In 1789, George Washington took eight days to travel the distance from his home in Mount Vernon to the scene of his inauguration in New York City. The eight days in itself is not significant. The important fact is that this is the same amount of time that it would have taken to travel that distance 1000 years before. There was no real progress in transportation in 20 centuries—since Moses or Nebuchadnezzar. Julius Caesar could have stepped from the first to the 19th century more easily than Ben Franklin into the next. Now, for the first time in history, no man dies in the same epoch in which he is born.

Understanding the future has always been central to warfighting strategy. Soviet Major General Sergei Kozlov said that "the most significant task of military science has always been defining the character of future war."

If we think back to when the Victorian era came to a close and the 20th Century came into view, would our predecessors have foreseen that in less than a single generation the greatest war in history would break out? Would they have they anticipated that in less than a single short career, they would see the emergence of the airplane, the tank, the submarine and the wireless radio -- systems that would transform forever the field of human conflict? Or would they have extolled the virtues of horse cavalry, observation balloons and the bayonet?

Much of the tragedy of the First World War stemmed from the inability of the military leaders of the day to grasp the implications of change. Their failure doomed an entire generation and led directly to a second, even more destructive global war.

It is our responsibility, that of each and every one of us, to do all in our power to see that we are ready for tomorrow, that we never, ever, allow complacency to take hold. In a very real sense that is why you are here. And make no mistake: the stakes you are playing for remain very high indeed.

What will the future look like? Almost certainly we will not face a hostile superpower in the near term, but the world will remain a dangerous place. There will be many who do not share our values, many who will challenge our interests, and many who will threaten our friends and allies. Some of these threats will look familiar. The nation-state, after all, will still be with us for a long time to come, and so will armies, navies and air forces much as we know them today.

But the 21st Century will also see the non-state actor come of age. Fanned by the ancient flames of ethnic, religious, cultural, and economic rivalry, many groups will challenge us at home and abroad. However, unlike past eras, terrorist groups and other non-state actors will have access to state-of-the-art technology. They will have secure communications and access to global positioning satellites, highly advanced computer technology and, perhaps most frightening of all, weapons of mass destruction. The proliferation of advanced technology with military applications has been so rapid and so pervasive that our enemies in the next century will have capabilities they could only dream about in this one.

And whether those enemies come in the form of nation-states, or rogue organizations pursuing their own agendas, they will have learned to challenge us asymmetrically -- not where we are strong, but where they think we are vulnerable.

Thus, preparing to respond to the full range of asymmetric threats should increasingly occupy our interest, our time, and our energy. Now is the time we should be doing that, now when we have a window of opportunity, when we don't have to worry about a strategic rival that could threaten our existence as a nation.

Our best thinking about how we should fight in the 21st Century is found in Joint Vision 2010, our conceptual template for future joint operations. Most of you are probably familiar with JV2010, at least in its broad outlines. The four pillars of Joint Vision 2010 are its key operational concepts: Dominant Maneuver, Precision Engagement, Focused Logistics and Full Dimensional Protection, and two "enablers" -- technological innovation and information superiority. Each of these are very powerful individually, but they are not ends in themselves.

The ultimate goal for joint warfighting in the future is decisive operations: the ability to win quickly and overwhelmingly across the entire range of operations, or in other words, Full Spectrum Dominance. We want our men and women to be the masters of any situation. In combat, we do not want a fair fight—we want capabilities that will give us a decisive advantage.

Implications

The implications of Joint Vision 2010 should be clear for us in the acquisition community. There are number of critical enablers that are absolutely essential to our ability to shape the international security environment and respond to the full spectrum of crises. Two of those are of special importance to us here today—harnessing advanced, complex technologies to achieve the desired Revolution in Military Affairs. And reengineering our acquisition process to meet the affordability challenge through a Revolution in Business Affairs.

Technology will need to be developed, tested, and sustained that can profoundly affect the warrior and leader who will execute 2010 missions.

Exploiting the Revolution in Military Affairs involves more than the acquisition of new military systems. It means leaping ahead technologically—not creeping ahead. It means harnessing these new technologies to give U.S. forces greater military capabilities through advanced concepts, doctrine, and organizations so they can dominate any future battlefield. And it means more than ever dealing with the complexity of a systems of systems approach.

The U.S. military's modernization effort is directly linked to the broader challenge of a Revolution in Business Affairs. Efforts to reengineer the Department's infrastructure and business practices must parallel the work being done to exploit the Revolution in Military Affairs if the nation is to afford both adequate investment in preparations for the future, especially a more robust modernization program, and capabilities sufficient to support an ambitious shaping and responding strategy through 2015.

I see our challenge as three-fold:

1. Conceiving, designing, developing, testing, producing, fielding, and supporting complex technologies that enable our new warfighting concepts.
2. Doing this in substantially less time. Our goal is to reduce cut the time from concept to fielding in half!
3. And doing so affordably—remarkable reducing not just the cost to acquire, but the total ownership cost.

Complexity

The nature of products and processes demanded by today's global market place is changing. So are the products required by our defense's warfighters and strategies. People often speak of the past as being a simpler time. We frequently emote that "things were not nearly as complicated." In light conversations, we "complain" that "back then" we didn't have to choose between paper and plastic, regular and decaf, or even between latte' and cappuccino.

It turns out that those conversations are not among persons who are imagining things. If you put today's economy under a microscope, the past really was a simpler time—at least from a product and process point of view. A recent found that the most successful commercial technologies

have changed in one basic way over the past quarter century: they have become more complex.

It looked at the 30 most valuable exports in the global market in 1970 and those of today. They found in 1970 nearly 60 percent of the world's top exports were essentially simple products that could be manufactured through simple processes. Today, that same percentage—60 percent—of the world's top exports are complex products that require complex manufacturing processes.

For example, 25 years ago, typewriters were one of the top products; now its PCs. And our audio players that were based on Thomas Edison's phonograph have been replaced by CD players that rely on computer chips and lasers. Certainly, those technologies that Joint Vision 2010 will rely on--low observable masking technologies, smarter weapons, long-range precision capability and information technologies—all technologies that were unknown a quarter century ago--are more complex than those of 25 years ago.

Put simply, the future belongs to those who can make sense of the complex, to those that can take an idea from conception through the functional integration of many complex technologies and disciplines to product realization, to those who can put complex technologies and products "out the door" and into the hands of users.

Today I will address five specific aspects of our strategy for meeting the RMA and RBA that I believe have particularly high leverage for us:

- Integrated Product and Process Development
- Simulation Based Acquisition
- Improved Software Engineering
- Design for Ownership
- Open Systems Approach

Integrated Product and Process Development

Success in this era will occur when different approaches and perspectives are brought together. The final value added is always greater than the sum of the parts. This places a premium on qualities that we sometimes undervalue as a society: qualities like diversity, trust and

community, and it requires that we develop an ability to bring together and reconcile those differing perspectives and approaches.

In order to do that, the Department has worked to find the best methods for reengineering its processes. In May 1995 the Secretary of Defense—then Bill Perry--directed a "fundamental change in the way we acquire goods and services" and mandated that the concepts of Integrated Product and Process Development (IPPD) and Integrated Product Teams (IPTs) "be applied throughout the acquisition process to the maximum extent possible."

The DoD defines IPPD as "a management process that integrates all activities from product concept through production/field support, using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives." An outgrowth of concurrent engineering practices, the IPPD process reflects a systems engineering approach that has incorporated sound business practices and commonsense decision-making. Fundamental to the successful implementation of the IPPD concept will be the willingness of organizations to undertake and experience profound changes in their cultures and past practices.

IPPD has had many successes in industry and it fits well within the spirit of the Department's acquisition reform initiatives. It is being accomplished by integrating the "functional stovepipes," utilizing best commercial practices, and encouraging teamwork within the Department and between ourselves and industry.

At the core of the IPPD implementation are Integrated Product Teams (IPTs) that organize for and accomplish tasks that acquire goods and services.

IPPD Key Tenets

To implement IPPD effectively it has been important for us to understand the interrelated tenets inherent in it.

The first of these is **customer focus**. The primary objective of IPPD is to identify and satisfy the customer's needs better, faster, and at less cost. The customer's needs should determine the nature of the product

and its associated processes. And to be precise, within DoD the customer is not the program manager, but the warfighter.

A second tenet is that **processes should be developed concurrently with the products** they support. It is critical that the processes used to manage, develop, manufacture, verify, test, deploy, operate, support, train people, and eventually dispose of the product be considered during product design and development. Product and process design and performance should be kept in balance to achieve life-cycle cost and effectiveness objectives. Early integration of design elements can result in lower costs by requiring fewer costly changes late in the development process. **Early and continuous life cycle planning** is essential.

Third, the government's interface with industry is critical to IPPD success. Our requests for proposals (RFPs) and contracts should provide **maximum flexibility** for employment of IPPD principles and use of industry's processes and commercial specifications, standards, and practices. They should also accommodate changes in requirements and incentivize industry to challenge requirements and offer alternative solutions which provide cost-effectiveness.

Fourth for IPPD, an event driven scheduling framework should be established which relates program events to their associated accomplishments and accomplishment criteria. An event is considered complete only when the accomplishments associated with that event have reached completion as measured by the defined criteria.

Proactive identification and management of cost, schedule, and technical risk is fundamental. Technical and business performance measurement plans, with appropriate metrics, should be developed and compared to best-in-class government and industry benchmarks to provide continuing verification of the effectiveness and degree of anticipated and actual achievement of technical and business parameters.

Without a doubt, the most essential tenet of IPPD is multidisciplinary teamwork. Inherently IPPD will not work without the people part, which brings us back to the diversity issue I mentioned earlier—previously separate communities working together—for common objectives. This is teaming. Integrated Product Teams are cross-functional teams that are formed for the specific purpose of delivering a product for an external or

internal customer. IPT members, as I must emphasize, should have complementary skills and be committed to a common purpose. The right people at the right place at the right time are required to make timely decisions.

Critical to the formation of a successful IPT are: (1) all functional disciplines influencing the product throughout its lifetime should be represented on the team; (2) a clear understanding of the team's goals, responsibilities, and authority should be established among the business unit manager, program and functional managers, as well as the IPT; and (3) identification of resource requirements such as staffing, funding, and facilities.

Also critical is empowerment. Decisionmaking should be driven to the lowest possible level commensurate with risk. The team should be given the authority, responsibility, an resources to manage its product and its risk commensurate with the team's capabilities. The authority of the team members needs to be defined and understood by the individual team members. The team, on the other hand, should accept responsibility and be held accountable for the results of its efforts.

I've spoken some about IPPD as a process and some about people, but let me shift to a third focus area: tools. It is incumbent on both DoD and industry to employ state-of-the-art methods and tools, to become knowledgeable of the capabilities of those tools, and to integrate them into their internal tools sets for planning, information management, design, cost trade-off analysis, and modeling and simulation.

And while various tools are important I would like to draw particular attention to virtual prototyping as a process for replacing physical prototypes by computational prototypes which can be embedded in realistic synthetic environments to support all phases of IPPD. This we are calling Simulation Based Acquisition.

Simulation Based Acquisition (SBA)

The Defense Department, in cooperation with our industry partners, envisions an acquisition process enabled by the robust, collaborative use of simulation technology that is integrated across acquisition phases and programs. The objectives of Simulation Based Acquisition (SBA) are to:

(1) Substantially reduce the time, resources, and risk associated with the acquisition process;

(2) Increase the quality, military utility, and supportability of systems developed and fielded; while reducing their operating and sustaining costs, and

(3) Enable integrated product and process development across the full acquisition life cycle.

I will not speak long on SBA since I know it will be addressed in some detail later this morning, but let me just state that I am convinced that there is consistent and pervasive evidence already accumulated regarding the value of a simulation-based approach to acquisition. Both commercial and military programs provide substantial proof of tangible results that can be measured in terms of improvements in **cost, schedule, productivity, and quality/performance.**

It is clear that integrated product and process development, backed by a strong commitment to computer-based modeling and simulation tools, provides a dominant and competitive edge in the commercial marketplace and a distinct warfighting advantage on the battlefield.

Software Engineering Improvement

Let me turn your attention now to an area of powerful leverage for the Department--software. There has been nothing like the headlong rush to software since the similar rush to electronics after WWI. The average automobile of today has more software in it than the first Apollo spacecraft to arrive at the moon 30 years ago.

We are just beginning to appreciate that a new breed of "knowledge warriors" is emerging—recognizing that knowledge can win, or prevent, wars. And this is causing fundamental changes in what is important to our warfighting capability.

In the Gulf War, television cameras, ravenous for dramatic visuals, focused on F-14s roaring off the decks of carriers, Apache helicopters swooping over the desert, M1A1 Abrams tanks growling over the sands,

and Tomahawk missiles singing out their targets. Pieces of hardware became overnight stars. But the real star was the invisible software that processed, analyzed, and distributed data, though no television watcher ever saw those who produced and maintained it—America's software soldiers.

Software is changing military balances in the world. Today weapons systems are mounted on or delivered by what we call "platforms"—a missile, a plane, a ship, or even a truck. And what we are learning is that cheap, low-tech platforms that are operated by even poor, small nations can now deliver high-tech smart firepower—if the weapons themselves are equipped with smart software. Stupid bombs can have their IQ raised by the addition of retrofitted components dependent on software for their manufacture or operation.

Costs of Software Failure

Information or knowledge superiority may win wars. But that superiority is exceedingly fragile. Pentagon leaders have been stunned in recent months, both by learning that some of our computer systems have been tampered with by hackers and by a recent military exercise, Eligible Receiver, that demonstrated how easy it is for hackers to cripple U.S. military and civilian computer networks.

But my issue for you here today is not so much one of information assurance—although that is decidedly a top priority for the Department. Rather I want you to focus on the implication that you succeed or fail on the software. It doesn't matter how much speed, or how much stealth or how much armor plating you have; you won't succeed if the software doesn't work.

So I contend that software that does not work is self-inflicted information warfare. And the policies, processes, and practices that guide the development and use of information technology in general, and software in particular, are a crucial component of knowledge strategy.

Expectations

Unfortunately our overall track record—or the perception thereof—for producing quality software is underwhelming. According to

the results of a study on U.S. software development reported by the Standish Group in 1996:

- In 1995, only 16 percent of software projects were expected to finish on time and on budget.
- An estimated 53 percent of projects will cost nearly 190 percent of their original estimates.
- Projects completed by the largest American organizations have only 42 percent of the originally proposed features and functions.

This sort of performance record might somehow be adequate in a word processor, but it hardly seems acceptable in a weapon system or where safety is a major consideration. After all, a soldier without a weapon is at best a tourist, and more likely a target.

Systems Engineering Process

When we track successful software developments, almost invariably the accomplishment can be linked to the existence of a good systems engineering processes. It is for this reason that my office is responsible for software acquisition policy in the Department. Not because we are the focal point for information technology—because we aren't. Not because we are the office of primary responsibility for software tools and technology—because we aren't either. But because it is the application of the disciplined systems engineering process that makes the difference between achieving the functionality we seek—in both hardware and software.

All of the primary systems engineering processes must come together for both hardware and software systems development. But I will highlight two specific aspects here: Requirements management and design for sustainability.

Requirements Management

I have a cartoon in my office that shows two individuals—presumably software engineers—with one of them saying to the other as he is running out, "You start coding, and I'll go find out what they want." Unfortunately there is all too much truth in this picture. Because what is being developed is "only software"—and everyone knows

software is easy to change—a disciplined requirements management process is all too frequently lacking. Without requirements analysis up front, however, the results are unsatisfied needs, wasted effort, and rework.

Software may be easy to change—at least relative to bent metal—but it can still be costly in both time and dollars. It is estimated that rework is 40 percent of the cost of development. Metrics collected by Capers Jones indicate that the cost and schedule impact of defects in requirements are the most expensive of all defects—followed by a defect in top level design (architecture), and finally by defects in code.

Design for Sustainment

Much of the software that is operational today will still be in service several years from now—with large implications for total ownership cost. By way of example, an assessment was made for the Air Force recently of the current process for updating the software in major operational weapon systems. Such software is embodied in formally designated Operational Flight Programs (OFPs). Over the service life of software intensive aircraft and smart munitions there is a need for continuous improvement, correction, and addition of new capability via software modification.

Over the FYDP, the combined B-1, F-15, and F-16 programs alone are projected to spend nearly one billion dollars on OFPs. When the planned expenditures for the B-2, F-22, F-117, and the advanced weapons are added in, the total five years costs of OFPs is nearly two billion dollars.

As I noted earlier, approximately 66 percent of DoD's software costs are associated with maintenance. Almost all of the systems engineering practices that have high leverage for lowering the cost of maintenance are practices that need to be implemented during development. These include development practices that reduce that density of defects in the software delivered into operation; effective software test; a strong configuration management program; and taking account early in the program of the engineering environment and processes that need to be in place for sustainment.

Design for Ownership

Of course, software is not the only component of systems that needs to be designed with sustainment in mind. A large area of leverage for the Department as we seek to reduce the total cost of ownership for our systems is what I will call "Designing for Ownership." Let me explain.

On the average, ninety percent of the cost of owning a weapons system is determined in the first few years of development—with sixty to eighty percent of that ownership cost being operations and sustainment. Acquisition costs—design, test, fabrication,...--are really only a relatively small fraction of total ownership costs.

Operations costs are driven by things like consumables—fuel, ammunition—and personnel, a large cost driver. Support costs are a factor of maintenance labor, repair materials, replenishment spares, and the like. These are all factors that are designed into the system we will own.

This is one of the reasons why acquisition logistics is so critical. Acquisition logistics is multi-functional, technical management discipline associated with the design, development, test, production, fielding, and sustainment, and improvement of systems. Its principal objective is ensuring that support considerations are an integral part of the system's design requirements, that the system can be cost-effectively supported through its life cycle, and that the infrastructure elements necessary for the initial fielding and operational support of the system are identified and developed and acquired.

Acquisition logistics activities are the most effective when they are integral to both the contractor's and the government's system engineering technical and management processes. When this is the case, system designers, acquisition logisticians, and program managers are best able to identify, consider, and tradeoff support considerations with other system cost, schedule and performance parameters.

The Open Systems Approach to Weapons System Design

Another one of the ways we can design with life cycle considerations in mind is the open systems approach to weapons system design which is both a technical approach and a preferred business strategy that allows DoD to field superior combat capability quicker and at a more affordable cost.

The open systems approach defines key interfaces for a system (or piece of equipment) being developed. Interfaces generally are best defined by formal consensus (adopted by recognized industry standards bodies) specifications and standards. However, commonly accepted (de facto) specifications and standards (both company proprietary and non-proprietary) are also acceptable if they facilitate utilization of multiple suppliers.

The use of de facto specifications and standards takes advantage of the fact that firms, particularly those in the commercial arenas, frequently develop hardware, software and systems standards of the design and fabrication of computing, telecommunications, display, sensing, and signal processing systems. Whether interfaces are described by consensus or de facto standards, the benefits only accrue if products from multiple sources are economically possible. Although the most common emphasis is on electronic systems, the open systems approach is widely applicable, from fasteners and light bulbs to jet engines.

An open systems approach is designed to facilitate the use of widely accepted, standard products-from multiple suppliers-in DoD weapons systems. In addition, if the architecture is defined by specifications and standards used in the private sector, the DoD can be one of many customers to leverage the benefits of the commercial marketplace, taking advantage of the competitive pressures which motivate commercial companies to reduce prices, and introduce new products developed with internal resources.

The open systems approach can have a profound effect on the life-cycle cost of a system. Program managers can have access to alternative sources for the key subsystems and components to construct DoD systems. DoD investment early in the life-cycle is reduced since at least some of the required subsystems or components are likely to already be available, or being developed without direct DoD investment. Production sources can be competitively selected from multiple competitors.

The system design flexibility inherent in the open system approach, and the more widespread availability of conforming commercial products, mitigates potential problems associated with a diminishing defense-dependent manufacturing base. Finally, life-cycle costs are reduced by a

long-lived, standards based architecture that facilitates upgrades by incremental technology insertion, rather than by large scale system redesign.

The system architecture should be addressed early in a program to maximize the number of potential solutions, and thereby help reduce program cost. By developing the architecture early in a program, the specific technology used in its implementation can then be chosen as late as possible.

The application of the open systems approach to legacy systems is less obvious but still beneficial. Legacy systems usually have size, space, power, cooling and shape factor constraints. For these systems, the open systems approach can provide form-fit-function interface (F3I) solutions within existing packaging, power, and environmental constraints. In such cases, the open systems solution frequently requires less system resources by using newer, more efficient technologies. The open systems approach is similar to F3I except that the open systems approach emphasizes choosing interfaces that are broadly accepted in the marketplace to allow for as many suppliers as possible over the long term.

Closing

At the end of the day we will field a Joint Force of unmatched capability and versatility. How good will we be? Let me paint a picture for you.

In the Joint Force of 2010, we'll be able to detect the launch of a ballistic missile, identify, target and attack the launch platform, alert all units in the impact area, and attack and destroy the incoming missile all in a matter of a very few seconds. The ability to transfer information that fast, across service and even national boundaries, in the fog and friction of war, using joint language that we all understand, will be nothing less than revolutionary.

Most of you are probably thinking this is General Shelton's job, or Secretary Cohen's, but it's really not. It's your job, because only you and your counterparts can make this happen on the battlefield. I expect every acquisition professional to be part of the team making our national strategy work—making Joint Vision 2010 a reality. Remember, your theme is "meeting the technology needs of the warfighter in the year 2000 and

beyond." Remember also that our challenges include not only meeting those technology needs, but doing so quickly and affordably.

I have discussed a number of strategies or initiatives that I believe will contribute to engaging those challenges—IPPD, Simulation Based Acquisition, improved software engineering, designing with total ownership in mind, and open systems approaches. Undoubtedly these strategies and others will be discussed in more detail here this week.

Because of the unprecedented opportunities and challenges emerging from the rapidly changing technologies enveloping us today, I cannot emphasize too much our need to work together to succeed. We must rely on each other now more than ever before.

The fact that our economy, and indeed our way of life, and certainly our defense, is now shaped and dominated by technological products of inordinate complexity means that we must see beyond the limits of our individual perspectives and achieve the breakthroughs that occur only through the synthesis of widely different skills and points of view. True progress within an envelop of complexity occurs only through an appreciation of mutual benefit.

Whatever our individual challenges, if we join our talents and work together, we can and will meet those challenges.

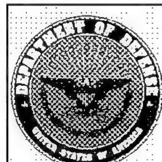
Many of the discussions on the agenda for this symposium will address what you are doing to "meet the technology needs of the warfighter." Peter Drucker has said that ours is a world in which knowledge, not labor, not raw materials, not capital, but knowledge, is the key resource . This meeting is your opportunity to increase your knowledge, and to share your knowledge. I strongly encourage you to take the maximum advantage of this opportunity.

4th Joint Avionics, Weapons, and Systems Support, Software & Simulation Symposium and Exhibition (JAWS S^3)

Mark Schaeffer

Deputy Director, Test, Systems Engineering, and Evaluation
Office of the Under Secretary of Defense (Acquisition & Technology),

June 16, 1998



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Test, Systems Engineering & Evaluation

Mark D. Schaeffer
Deputy Director

OUSD(A&T)/DD,TSE&E/SE
Room 3D1075, Pentagon
Washington, DC 20301

(703) 697-6329
FAX 614-9884
mschaeff@acq.osd.mil

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DTSE&E Mission

~

- Ensure effective integration of all engineering disciplines into the system acquisition process:
  - design
  - production
  - manufacturing and quality
  - acquisition logistics
  - modeling and simulation
  - and software engineering

- Oversight of DoDís Major Range
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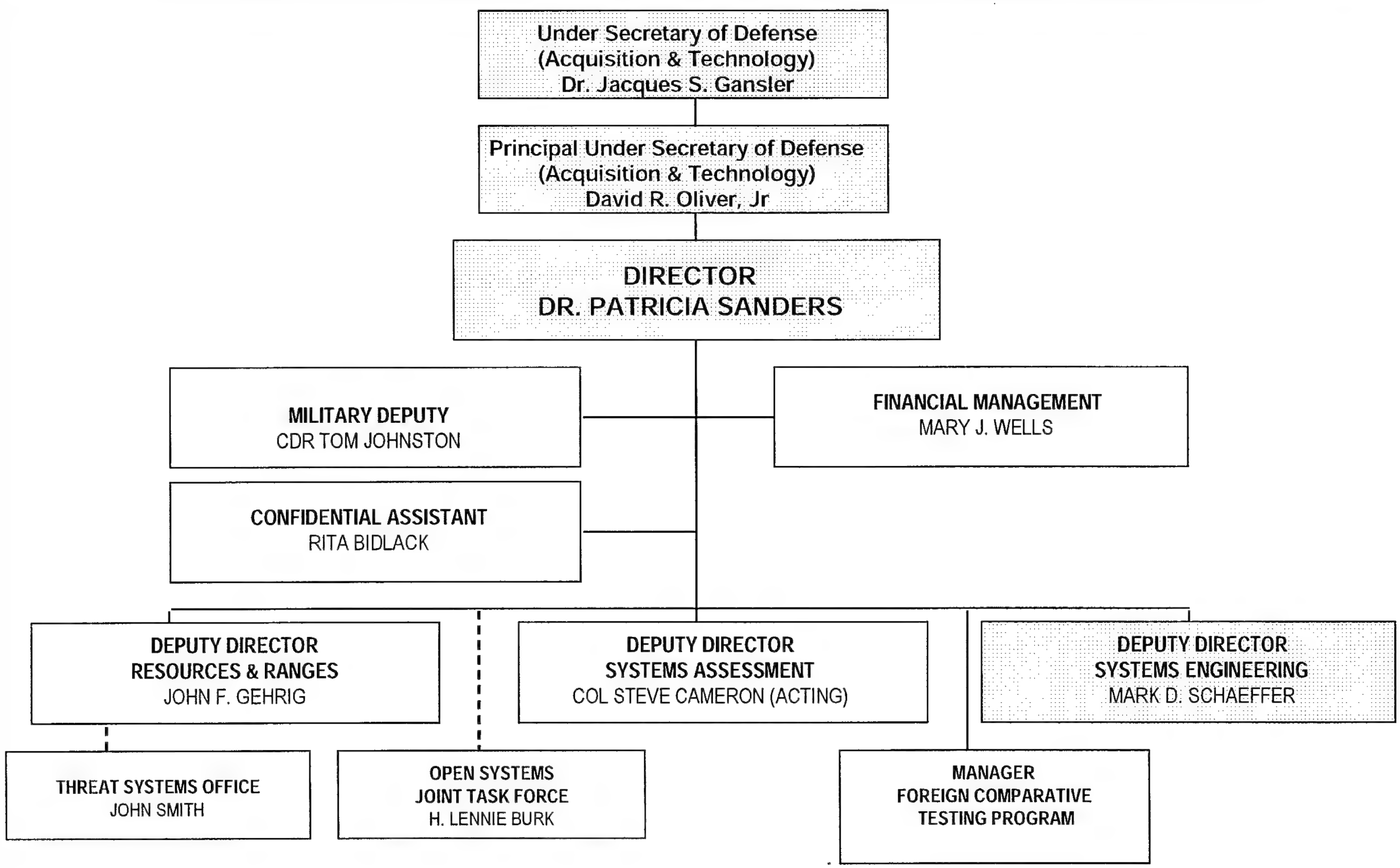


PDUSD(A&T) "Concept of Operations" for Systems Engineering

The systems engineering mission will provide policy and support for the early **integration** of functional disciplines in the acquisition process. This will assure consideration of the most effective and efficient application of risk reduction methodologies and to **facilitate communications** between members of our acquisition community and our warfighter users.

PDUSD(A&T) MEMO OF 28 October 1994

Systems Engineering Directorate

- Director, Test & Evaluation (D,T&E) mission expanded to **include Systems Engineering** (D, TSE&&E)
- Systems Engineering (SE) Directorate was established and assigned **Policy and Procedure** responsibilities for:
  - Systems Engineering
  - Risk Management
  - Quality
  - NATO/International Quality
  - DAWIA (TRAINING)
  - Test & Evaluation (June 97)
  - Manufacturing & Production
  - Acquisition Logistics
  - Value Engineering
  - Reliability & Maintainability
  - Software
  - Modeling & Simulation (June 1997)

Institutionalize IPPD in DoD...DMC, April 1995

DoD Acquisition Reform - MAJOR GOALS

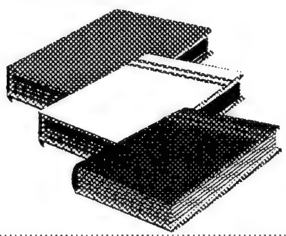
- Enhance the needs determination process (i.e., the requirements)
- Improve the system acquisition process*
- Improve the procurement process
- Improve contract administration
- Improve Government contract terms and conditions
- Change the culture
- Define measures of success - METRICS

DUSD-AR, June 1994

**** Improve the software procurement process***

Background: Two Revolutions Are Occurring in DoD

1997: 3 Major DoD Documents



QDR
DRI
NDP

Common reform principles

- Focus enterprise on unifying vision
- Commit ldrship team to change
- Focus on core competencies
- Streamline orgs for agility
- Invest in people
- Breakdown barriers between orgs
- Exploit info technology

QDR	Quadrennial Defense Review
DRI	Defense Reform Initiative
NDP	National Defense Panel

What we Buy - Revolution in Military Affairs

- **Build on new warfighting concepts of Joint Vision 2010**
- **Exploit technology to achieve**

How we Buy - Revolution in Business Affairs

- **Take advantage of Business process improvements pioneered in private sector**
- **A must, to maintain competitive edge in changing global security arena**

4

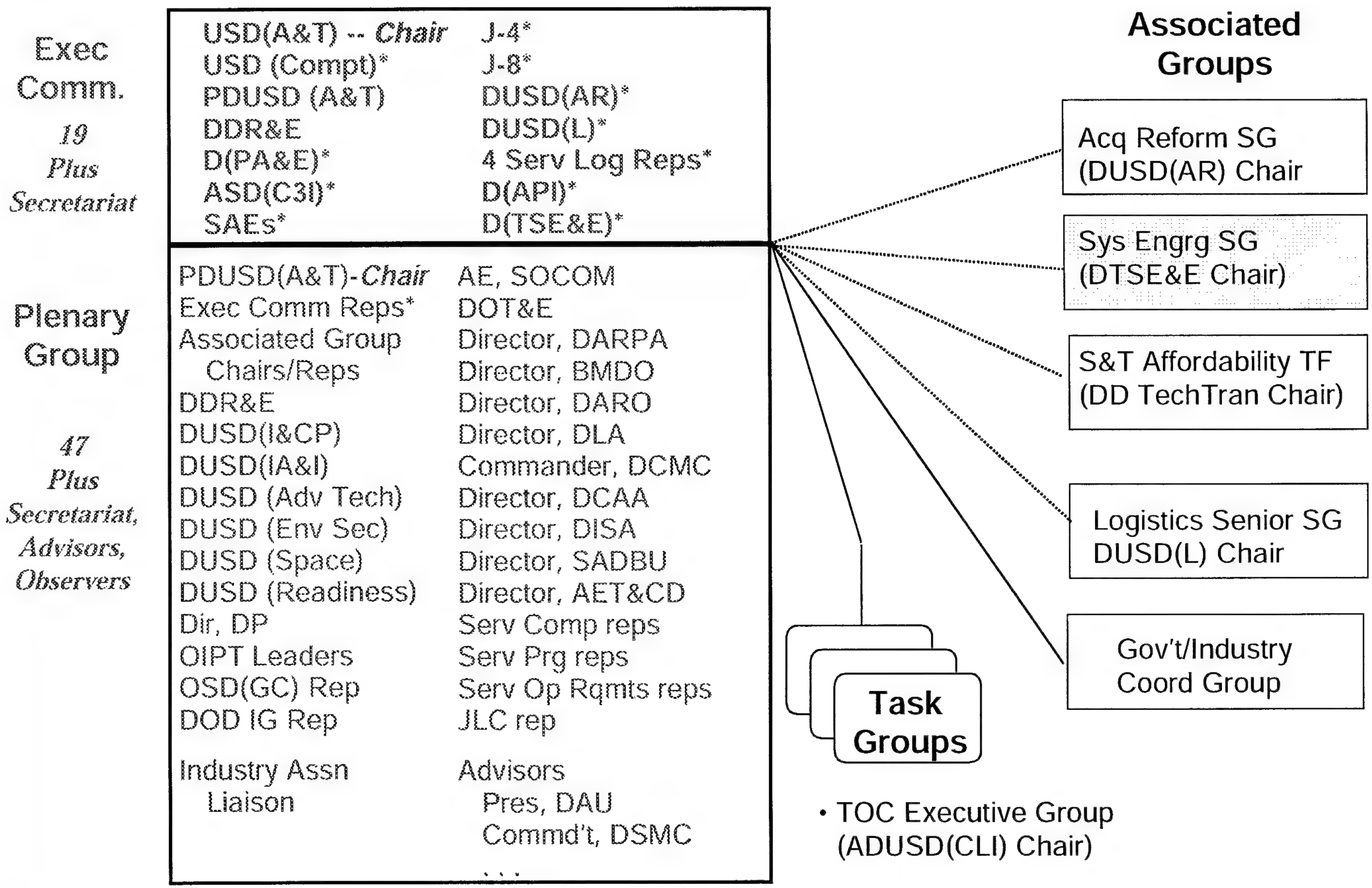
The Goals

Vice President's National Performance Review -
Cut delivery time for new systems by 25%

Department of Defense -
- Stretched goal to 50% reduction of cycle time
- Set goal to reduce Total Ownership Cost (TOC)

Defense Systems Affordability Council -
- Recognized potential of M&S
- Set SBA as one of the top initiatives to realize the stretch goal

Defense Systems Affordability Council (DSAC)



* Exec Comm members/reps also participate in Plenary Group

4, 2

DSAC Guidance

- DSAC Vision: "Reduce Total Ownership Cost (TOC) and cycle times to meet modernization and readiness needs within realistic budget constraints, while enhancing military capability."
- Actions in three areas to support vision:
  - For reducing TOC, designate pilot programs that will set ambitious goals
  - For reducing cycle time, evaluate alternative acquisition models & attach elements of sustainment cycle times
  - Realistic programming & program stability are essential - integrated team efforts by requirements, programming & acquisition communities

SESG's Top Priority Activities in Support of the Three DSAC Areas

- Simulation-Based Acquisition (planned)
  - Robust, collaborative use of simulation technology that is <u>integrated across phases & programs</u>
  - Joint task force six-month effort to develop a roadmap to migrate from current environment to SBA environment
- Software initiatives
  - Focus on integrating software technical & management policy, guidance & metrics
- Open systems
  - Examining expansion of Joint Technical Architecture (JTA) beyond C4I interoperability
- Performance-based business environment
  - Joint Aeronautical Commanders Group guidance for operating effectively in a performance-based environment
  - Deploy in Deskbook (Mar 98*) & Defense Acquisition University (in progress)
- Integrated Process and Product Development (IPPD) Handbook
  - Expands on guidance in ìIPPD guideî for program offices & industry; provides examples of specific ways to implement IPPD on programs; publish 3QFY98

Establish detailed plans and metrics

IPPD Versus Systems Engineering

- IPPD
  - A management technique that integrates systems acquisition functions, using interdisciplinary teams to optimize the process

- Systems Engineering
  - Provides a structured approach addressing the technical aspects of a program within an IPPD framework

IPPD Tenets

- Customer focus
- Concurrent development of products and processes
- Early and continuous life cycle planning
- Proactive identification and management of risk
- Event driven scheduling
- Encourage robust design and improved process capability
- Multidisciplinary teamwork
- Empowerment
- Seamless management tools
- Maximize flexibility for optimization and use of contractor-unique approaches

What is DoD's Role with IPPD

- When Industry is charged with System Development: PEO/PM should understand IPPD concepts and suggest criteria that enable DoD to craft RFP contracts that foster and reward effective application of IPPD process.
- When a PEO/PM or other Agency is charged with system development: PEO/PM/Agency should not only understand system acquisition management concepts but also technical concepts of IPPD to tailor their respective programs.
- An IPPD approach to system modifications in organic installations could improve shipyards, depots, logistics center engineering and management processes.

DoD has a need to both do IPPD and manage the IPPD process

System Acquisition Elements

MANAGING THE JOB...

- H IPPD
- Planning/Estimating
- Work Breakdown Structure
- Contracting
- Personnel/Resources
- Integrated Program management
- Engineering Management
- Requirements Management
- Interface Management
- Configuration Management
- Policy
- Licenses
- Logistics
- Training

DEVELOPING PRODUCT...

- H IPPD
- Product Lines
- Modeling/Simulation
- Design
- Integration
- Trade-off Studies
- Open Systems
- Continuous Process Improvement
- Reliability
- Interoperability
- Producibility
- Maintainability
- NDI
- GOTS/COTS

ASSURING PRODUCT...

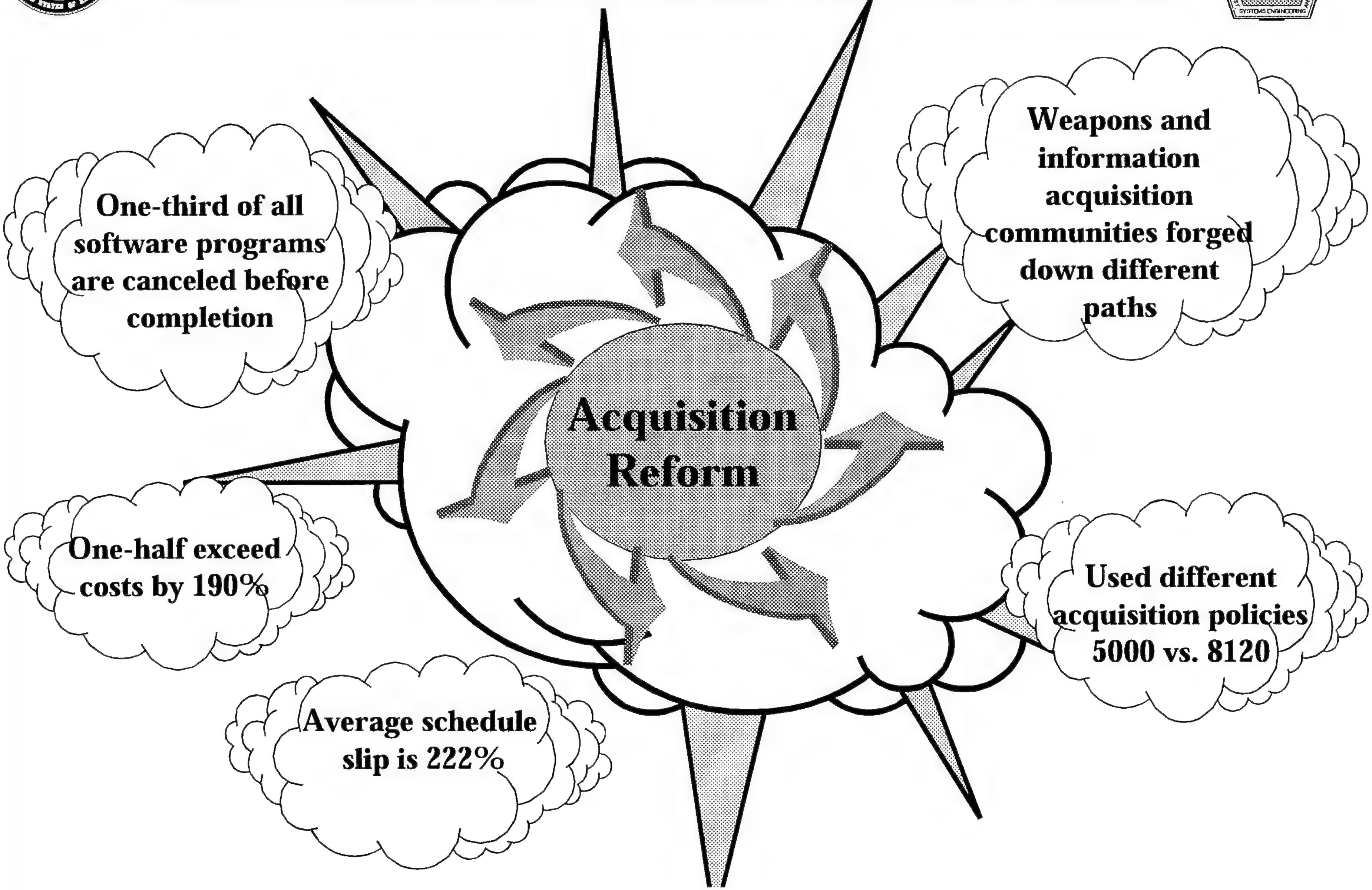
- H IPPD
- Quality
- V&V
- Inspections
- Measurement
- Tracking
- Sustainment
- Supportability
- Traceability
- Test & Evaluation
- Safety

Special Considerations...

- Architecture
- Programming Languages
- Modification/Upgrade
- Post/Deployment Support

Pre-Acquisition Reform

Pre-Acquisition Reform Environment



DoD Acquisition Management Key Policies

DoDD 5000.1
Defense Acquisition

"Software is a key element in DoD systems. It is critical that software developers have a successful past performance record, experience in the software domain or product line, a mature software development process, and evidence of use and adequate training in software methodologies, tools, and environments."

DoDD 5000.1, para 2.k

DoD 5000.2-R
Mandatory Procedures for MDAPs and MAIS

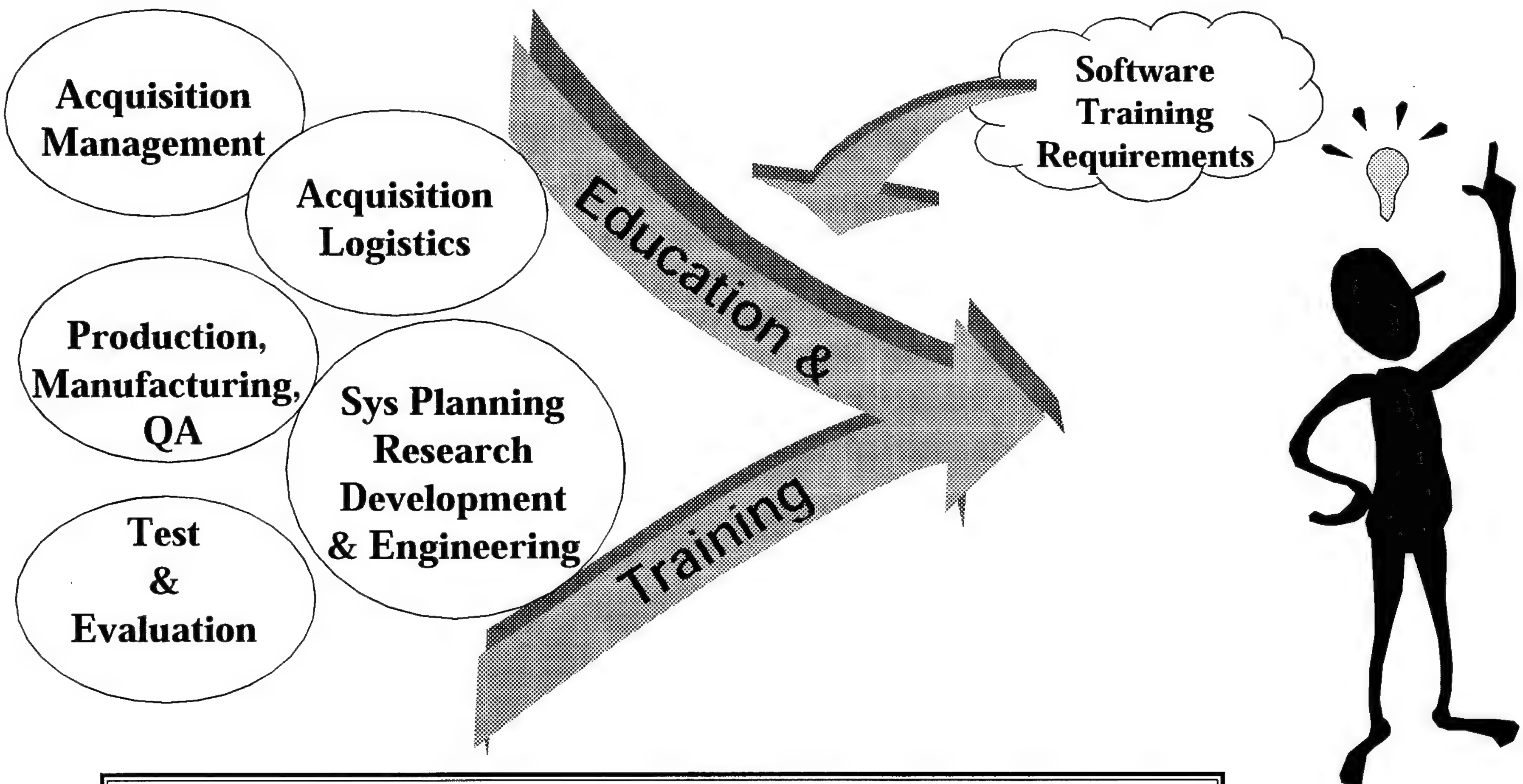
"Software shall be managed and engineered using best processes and practices that are known to reduce cost, schedule, and performance risks. It is DoD policy to design and develop software systems based on systems engineering principles...

DoDD 5000.2-R, para 4.3.5

...to include:

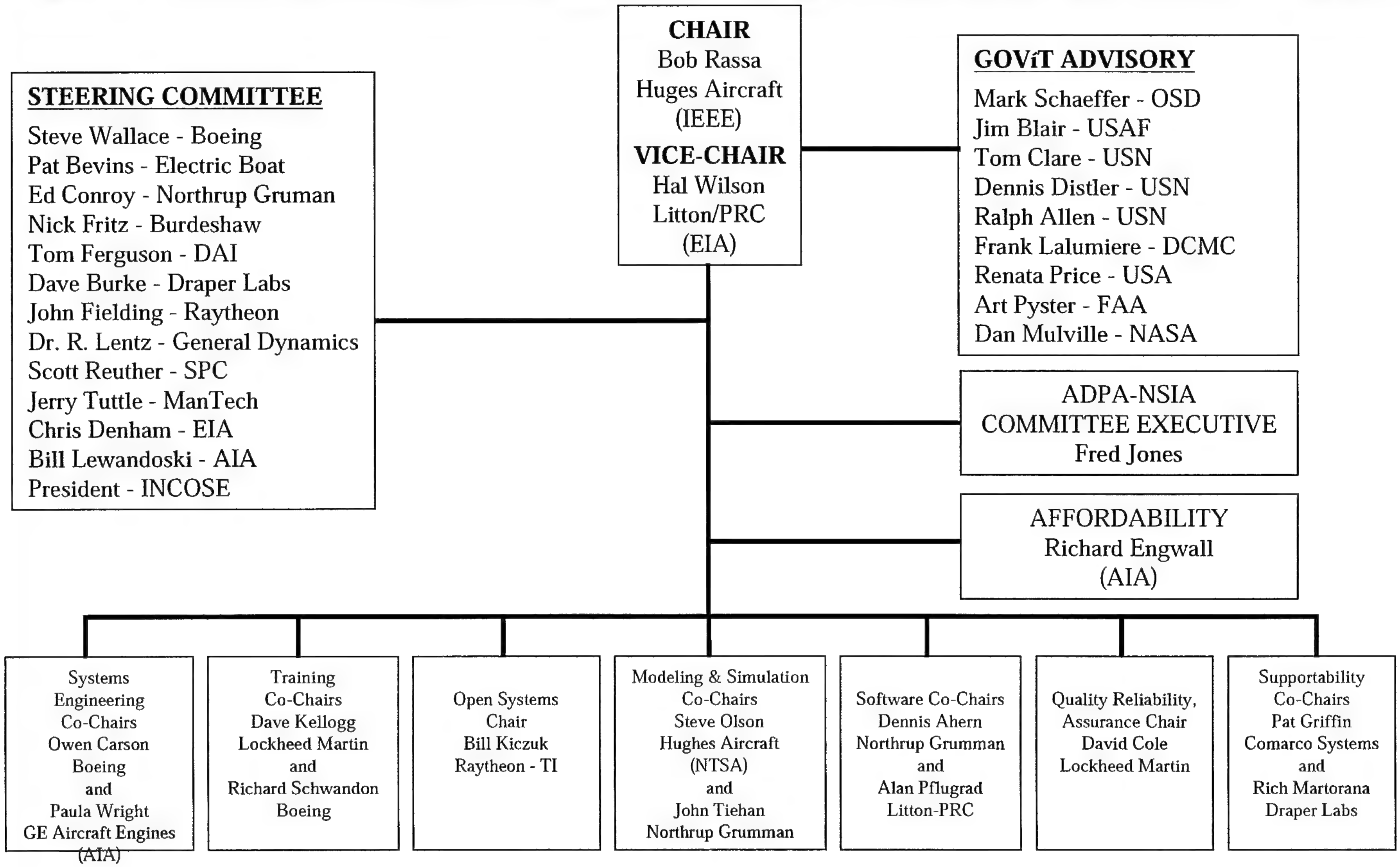
- *Developing software system architectures that support open system concepts*
- *Exploiting COTS products*
- *Identifying & exploiting s/w reuse*
- *Selecting a programming language in the context of systems and software engineering factors (ASD(C3I) memo, April 29, 1997)*
- *Use of DoD standard data (DoDD 8320.1)*
- *Selecting contractors with:*
  - *domain experience in comparable systems*
  - *successful past performance record*
  - *demonstrable mature software process*
- *Use of software metrics*
- *Assessing information warfare risks IAW DoDD TS-3600.1*

Our Education & Training Goal



Our Goal: ***A Workforce which can take advantage of the Acquisition Process Improvements we are Implementing***

NDIA
Systems Engineering Committee



In Summary

- Acquisition Reform affects the entire Department and will continue to do so into the future - including Legacy System Modernization and Maintenance
- Hardware and Software acquisition have a lot in common, and should be treated as a SYSTEM
- Software unique issues/considerations will continue to be worked
- We now have common acquisition policy and practices (i.e., 5000 series and the Defense Acquisition Deskbook) ...applicable to Legacy Modernization and Maintenance
- Policy and culture will continue to evolve

We must now focus on how to effectively apply Acquisition Reform lessons learned to maintaining and upgrading our existing systems.

SBA and T&E Panelists

Ms. Robin Frost

Systems Engineer,
Directorate of Test, Systems Engineering, and Evaluation
Office of the Under Secretary of Defense for Acquisition & Technology
Washington, DC

Mr. Michael Smith

Avionics Lead Systems Engineer
F-22 Systems Program Office
Wright Patterson AFB, OH

Mr. Richard Bayard

Assistant Program Manager
Advanced Amphibious Assault Vehicle
Woodbridge, VA

CDR Hamman

CVX Aviation Maintenance Support Analysis Lead
Naval Air Systems Command
Patuxant River, MD

Backups

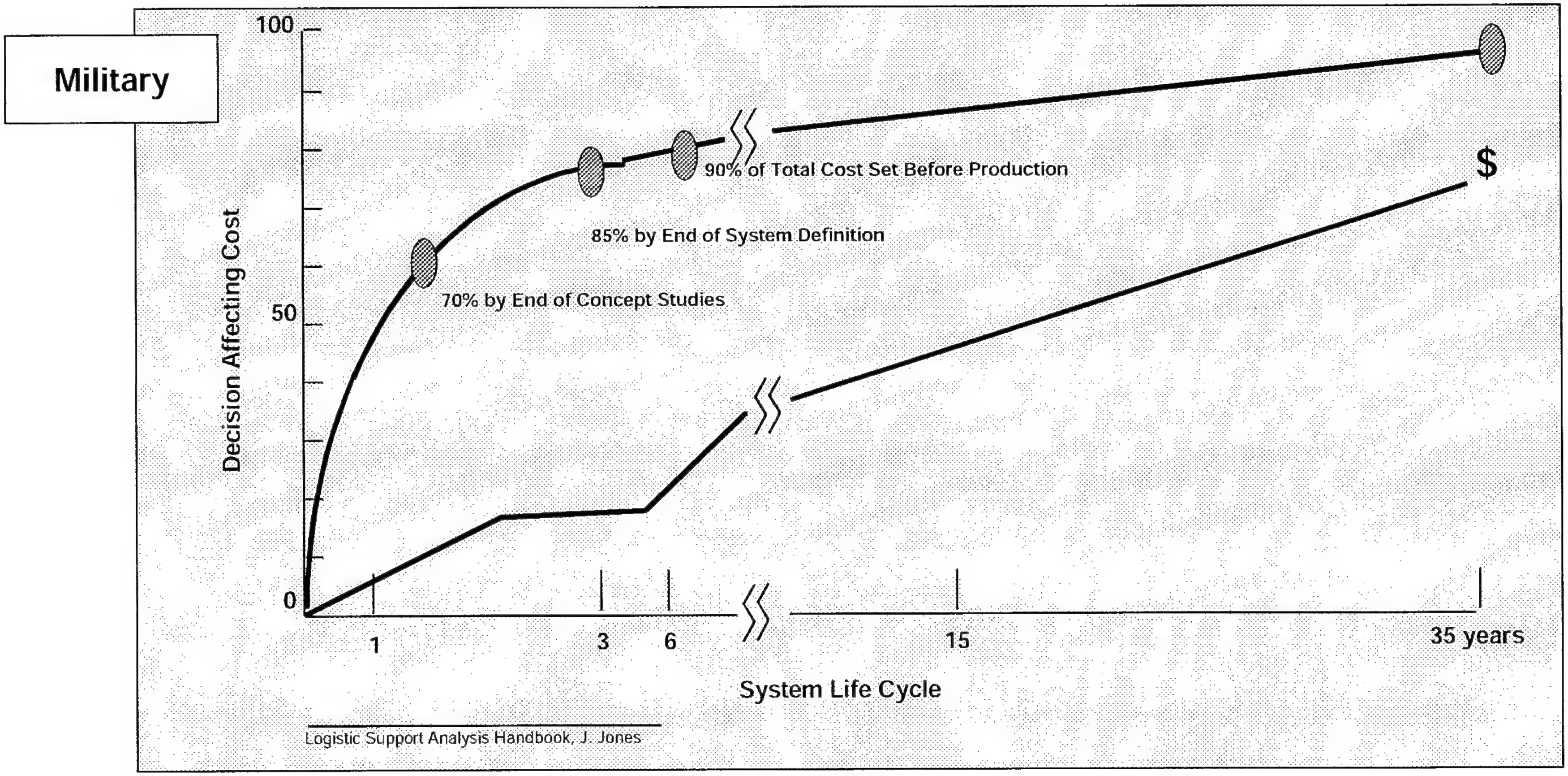
Purpose

Discuss latest initiatives, objectives, priorities for using M&S to support acquisition

Outline

- Simulation-Based Acquisition Initiative
- Simulation, Test, and Evaluation Process (STEP)

Where is Cost Determined?



Life-Cycle Costs Are Locked in During the Up-front Design and Development Process

The Problems in Acquisition

- It currently takes up to 15 to 20 years to develop and field a weapon system.
- Costs are not managed aggressively. The majority of program costs (90%) are set within 6 years of development.
- Operations and support (O&S) costs are not fully planned or understood.
- Full potential of Integrated Product and Process Development (IPPD) not realized.

Increasing Emphasis on M&S

Navy, February 1997:
M&S Master Plan

Army (SARDA), May 1997:
Simulation Support Plan Guidelines

Air Force (SAF/AQ), November 1997:
M&S in Support of Air Force Acquisition Programs

USD(A&T) Memorandum, March 16, 1998:

- "...it is essential that we plan for the use of M&S in our acquisition strategies."
- "I expect programs to make the up front investment in M&S application and technology and will be looking for evidence of that investment in program planning and execution."

M&S in Acquisition Today - Metrics

Cost

- LPD-17 saved $6 million in design; and eliminated 100 tons topside weight due to the use of M&S technology
- JSF virtual manufacturing efforts may save 3 percent life cycle cost (could translate to $5 billion)

Schedule

- "Big three" auto manufacturers reduced concept approval to production time from 5 to 3 years
- Electric Boat able to halve time required for submarine development, from 14 to 7 years

Productivity

- 38 Sikorski draftsmen took six months to develop working drawings of the CH-53E Super Stallionís outside contours; with M&S, 1 engineer accomplished the same task for Commanche helicopter in 1 month
- 14 engineers at Tank and Automotive Research and Development Center designed low-silhouette tank prototype in 16 months; (3 years, 55 engineers by traditional methods)

Quality and Performance

- Northrop's CAD systems first-time, error-free, physical mockup of many sections of B-2 aircraft
- Navy's Next Generation Attack Submarine reduced standards parts list to about 16,000 items from 95,000 items for earlier Seawolf-class submarine

SIMULATION BASED ACQUISITION & SIMULATION TEST AND EVALUATION PROCESS

MS. ROBIN FROST

OFFICE OF THE
UNDER SECRETARY OF DEFENSE (ACQUISITION & TECHNOLOGY),
SYSTEMS ENGINEERING

June 16, 1998

Office of the Under Secretary of Defense
(Acquisition & Technology)
Test, Systems Engineering & Evaluation

Robin L. Frost
Systems Engineer

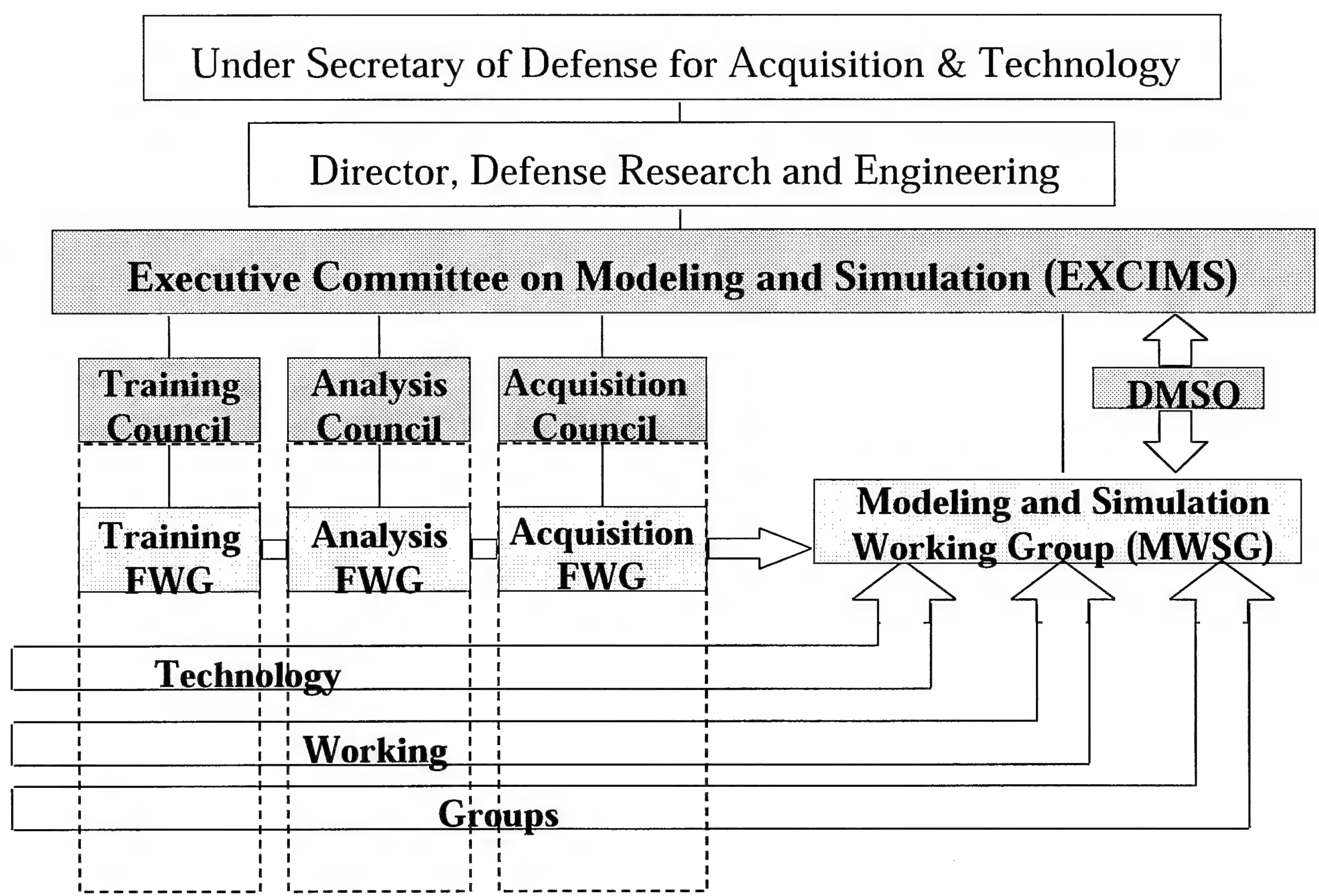
OUSD(A&T)/DTSE&E/SE
Room 3D1075, Pentagon
Washington, DC 20301

(703) 695-2300
FAX 614-9884
frostrl@acq.osd.mil

Topics

- Simulation Based Acquisition Initiative
  - Background
  - Why do we need it?
  - What is it?
  - How will we get it?
- Simulation Test and Evaluation Process

DoD M&S Management Structure



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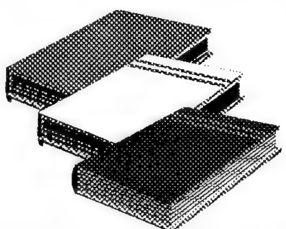

QDR
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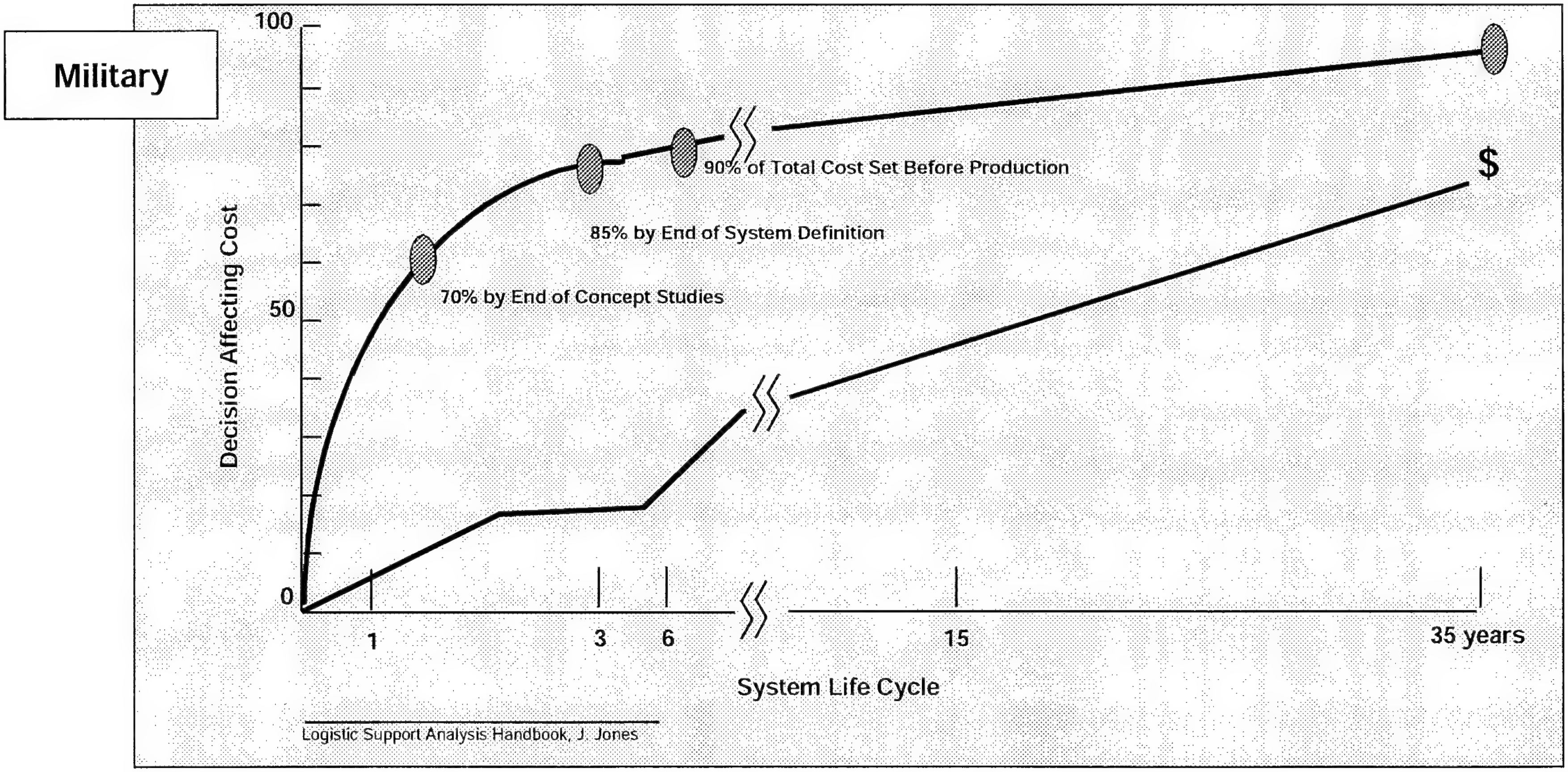
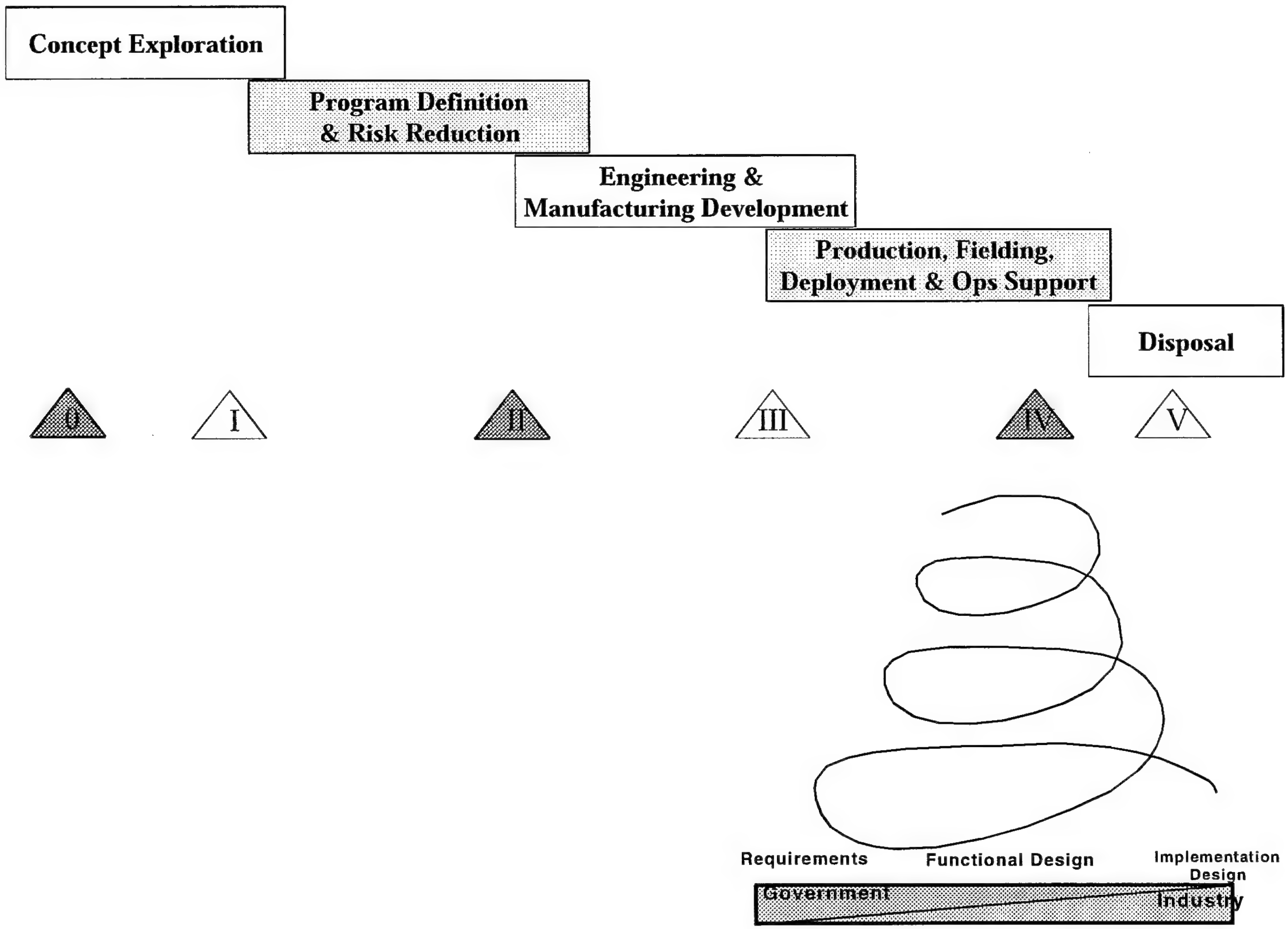


Life-Cycle Costs Are Locked in During the Up-front Design and Development Process

Comparison of Traditional Acquisition and Simulation Based Acquisition



Background:

Known Benefits of M&S

Consistent and Pervasive Evidence that M&S used Effectively Provides Substantial, Quantifiable Benefit as Measured in:

- Cost
- Schedule
- Productivity
- Quality and Performance

Final Report: *Study on the Effectiveness of Modeling and Simulation in the Weapon System Acquisition Process*
http://www.acq.osd.mil/te/pubdocs/acqstudy.htm

Background:

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Background:

M&S Required in Acquisition

DoD Directive 5000.2:

- "Accredited M&S shall be applied, as appropriate, throughout...the system life-cycle..."
- "PMs shall integrate...M&S within program planning...;
- "...and plan for life-cycle application, support, and reuse M&S,
- "and integrate M&S across...functional disciplines."

DoD is Committed:
Better Ways to Determine What to Buy; Better Methods of Buying What it Needs

DoDD 5000.2-R Part 4.2:

PMs shall employ the concept of Integrated Product and Process Development (IPPD) throughout program design. Integrated Product Teams, a key tenet of IPPD, shall be used to integrate all activities from concept development through production and field support

M&S is an Enabler of the IPPD concept

- integration of complex systems,
- design trades,
- identify technical and operational challenges early on,
- virtual prototypes in realistic, synthetic environments for a shared vision of a proposed system

Example: before - elaborate wooden mock-ups of submarines

after - first-ever virtual design review of newest submarine, with a computer-generated sailor climbing the ladders, reaching for hatches, and performing maintenance functions to test the viability of our design, all before physical prototypes were built

Öbut, if weíre talking about a revolution,
this isnít enough.

Why?:

A Call for Change

"The objectives of the [weapons acquisition] changes must be these: higher-quality weapon systems that fail less often and are easier to maintain, far less expensive weapon systems that will still have the high performance needed to maintain the technological leadership that is the essence of America's defense strategy, and more rapid fielding of new weapon systems (so that advanced technology can be brought to bear in sufficient quantity to make a difference in the outcome of a conflict)."

Affording Defense
Honorable Jacques S. Gansler, USD(Acquisition and Technology)
Cambridge, Massachusetts: The MIT Press, 1991.

Simulation Based Acquisition - Why?

Acquisition Today
M&S Within Programs

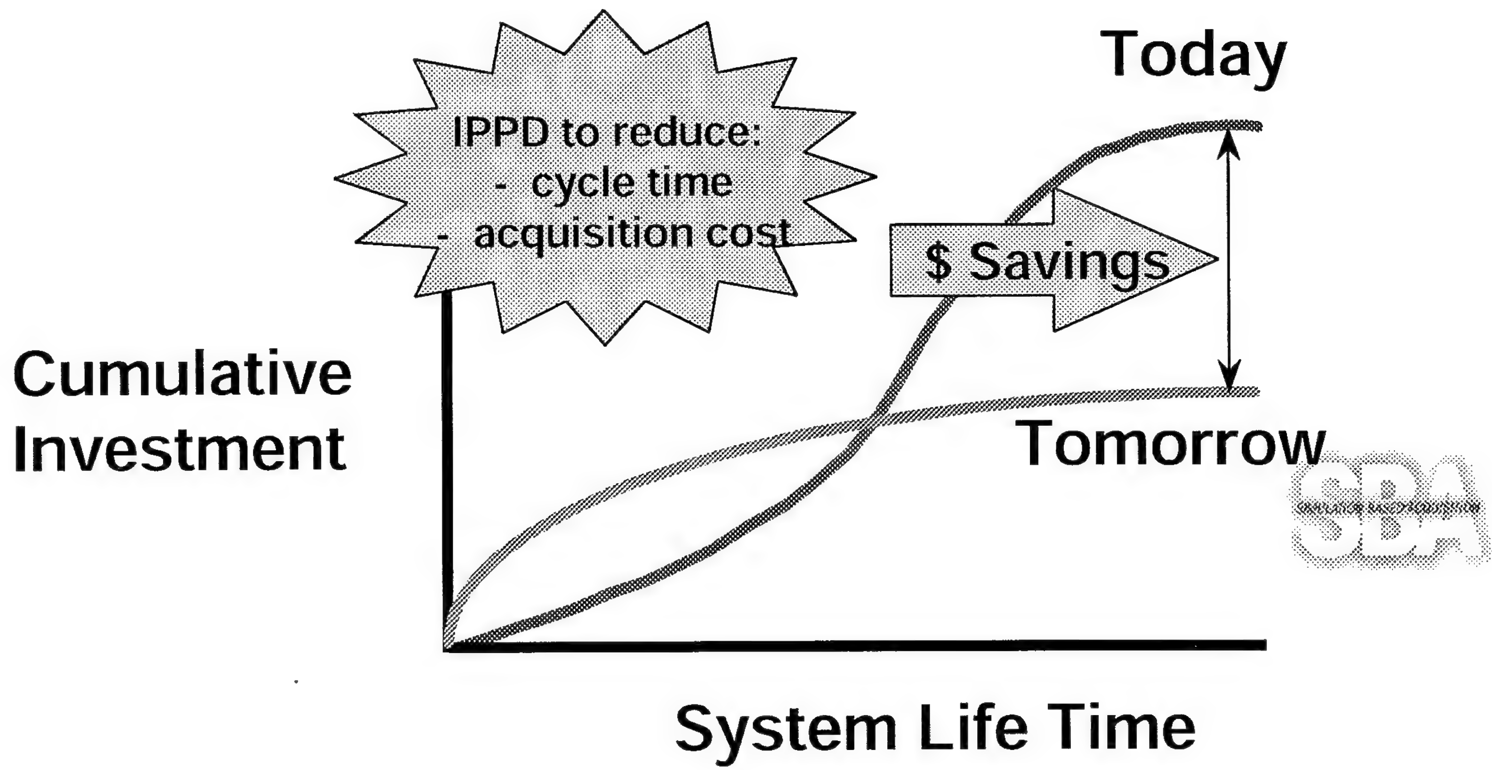
- Full potential of IPPD not realized
- 8-10 year design cycles; 15-20 years to field
- 90% of program costs set before MS II
- O&S costs not fully planned
- Rapid, affordable system updates necessary

Supporting M&S Characteristics

- Highly specialized tools
- Limited reusability
- Not used across all program areas
- Limited scope
- Unique data representations
- Limited interoperability

Why?:

SBA Payoff



What?:

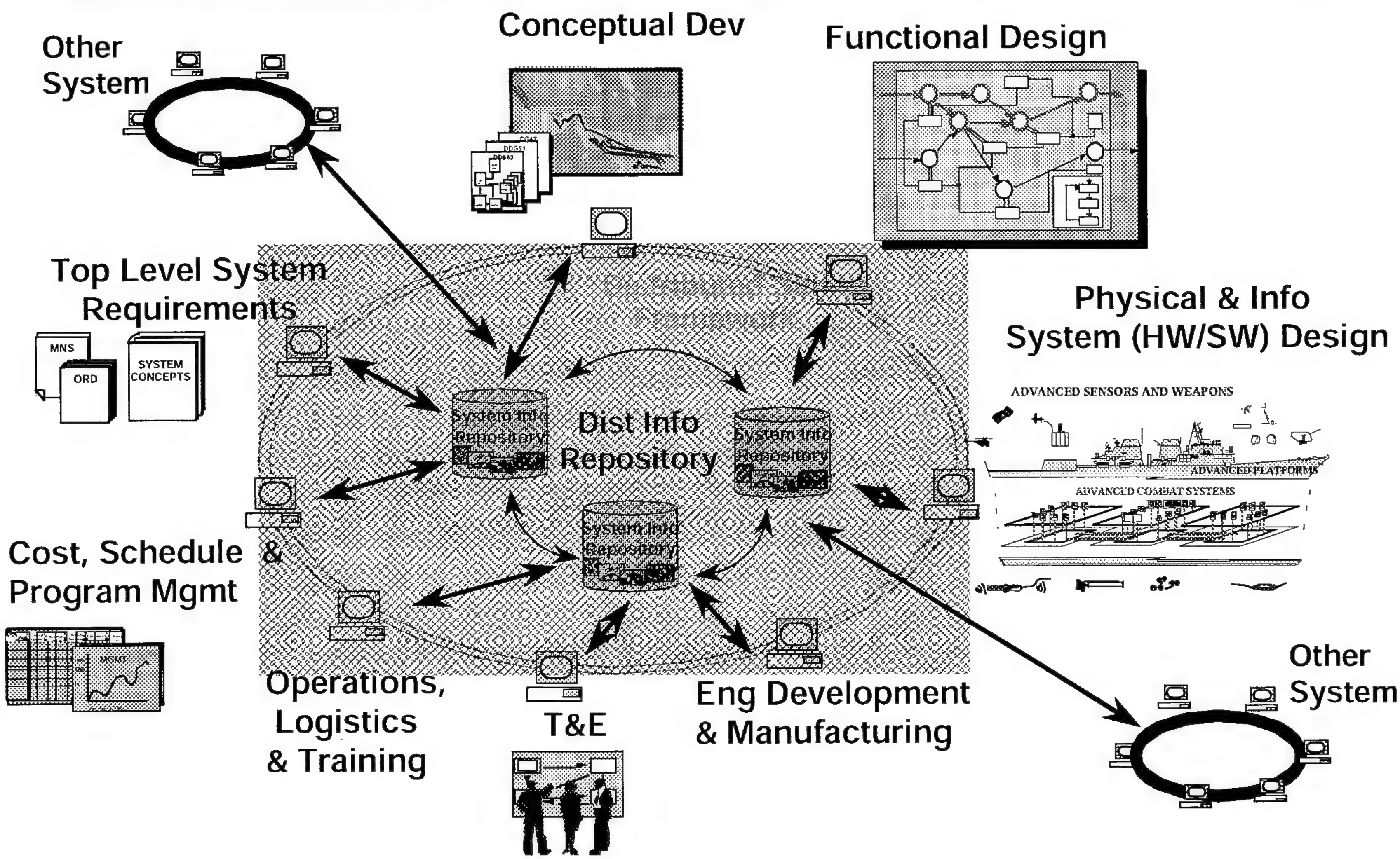
Simulation Based Acquisition (SBA)

...to have an Acquisition Process in which DoD and Industry are enabled by robust, **collaborative use of simulation technology** that is **integrated across acquisition phases and programs**.

- Substantially **reduce the time, resources and risk** associated with the entire acquisition process;
- **Increase the quality, military worth and supportability** of fielded systems, while **reducing** their **operating and sustaining costs throughout the total life cycle**;
- Enable Integrated Product and Process Development (IPPD) **across the entire acquisition lifecycle**.

Why?:

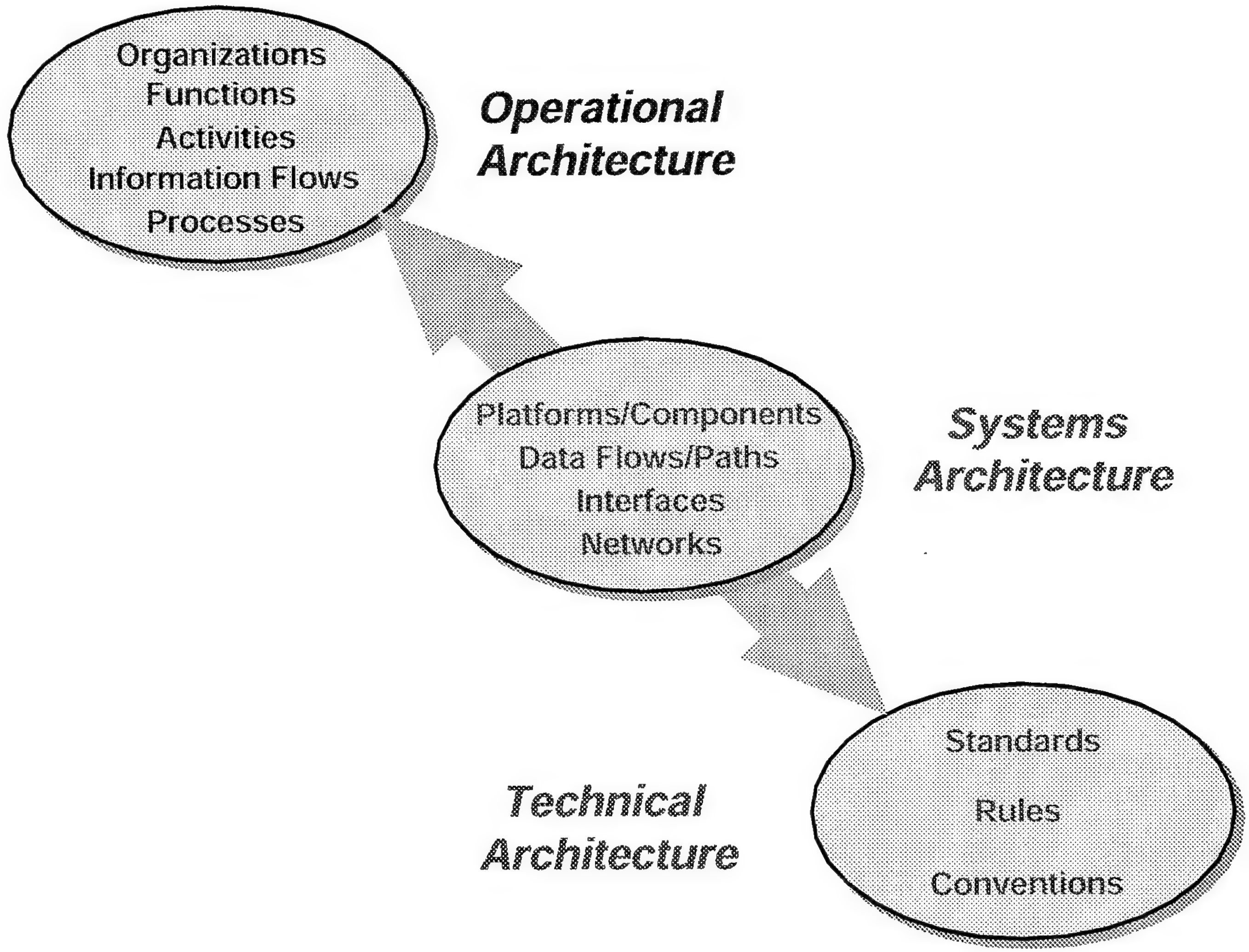
SBA Concept of Operations Illustration



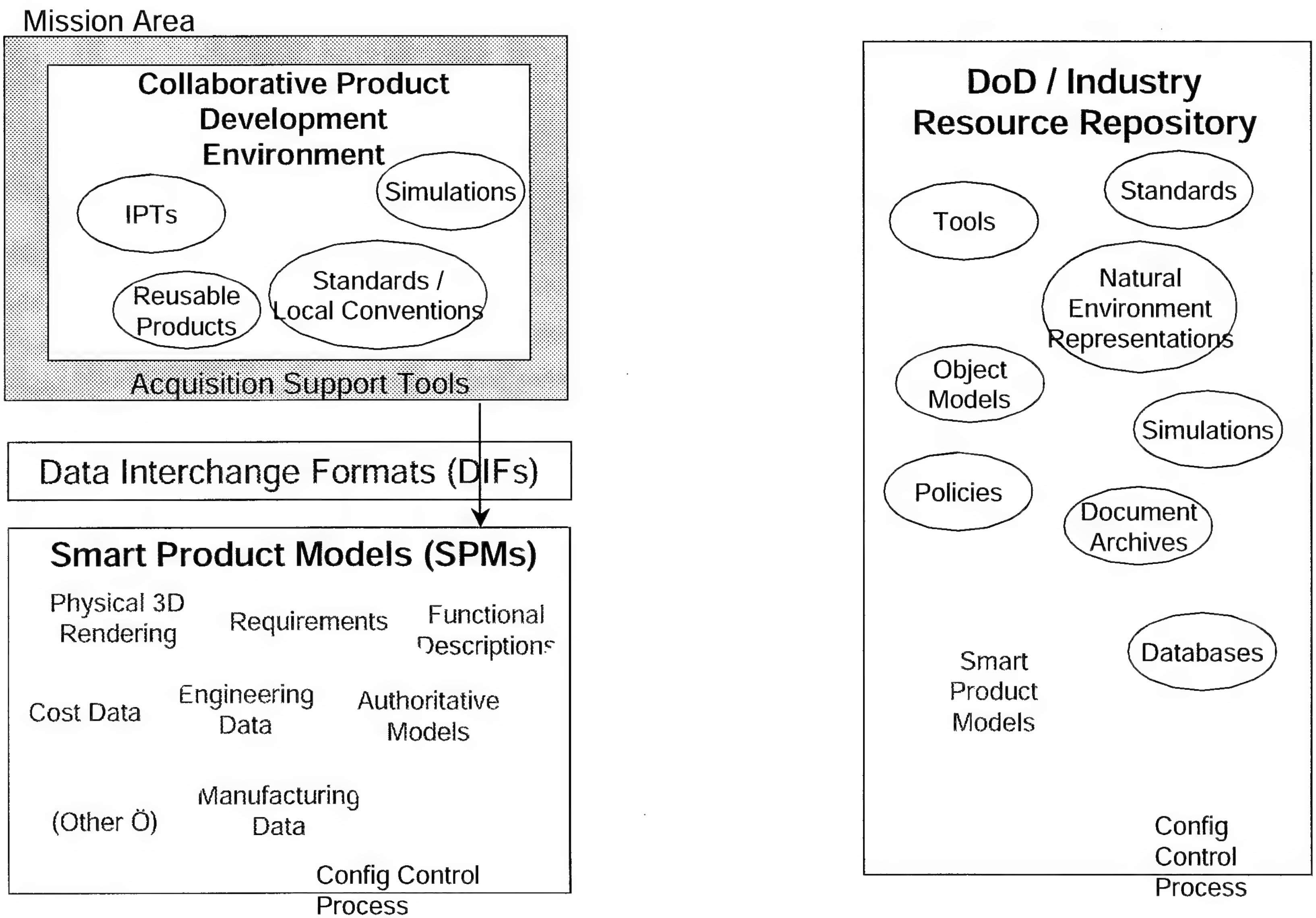
Extensive Re-use Within Phases and Across Acquisition Programs

How?:

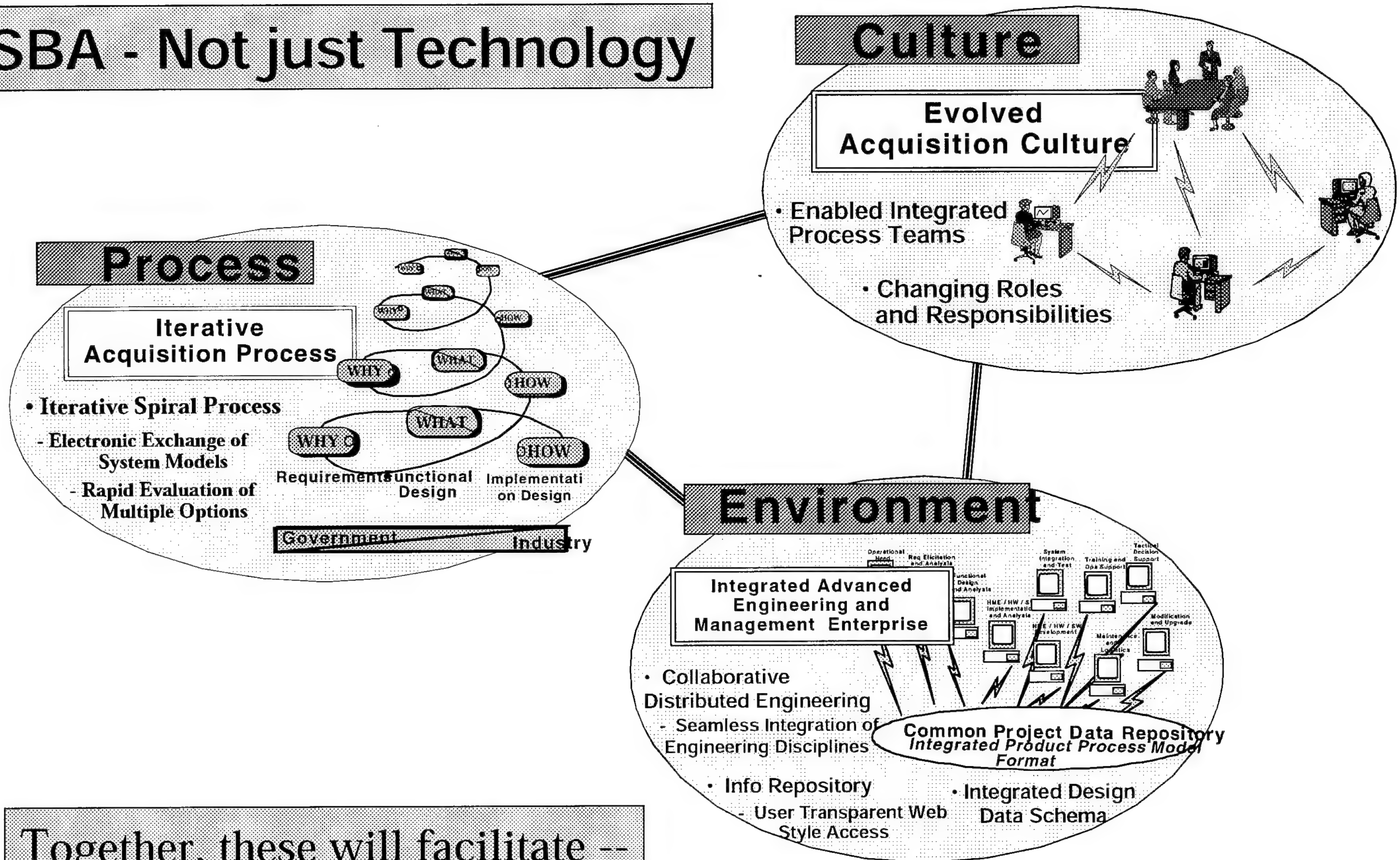
SBA Architecture Views



SBA Systems Architecture (To-Be)



SBA - Not just Technology



Together, these will facilitate --

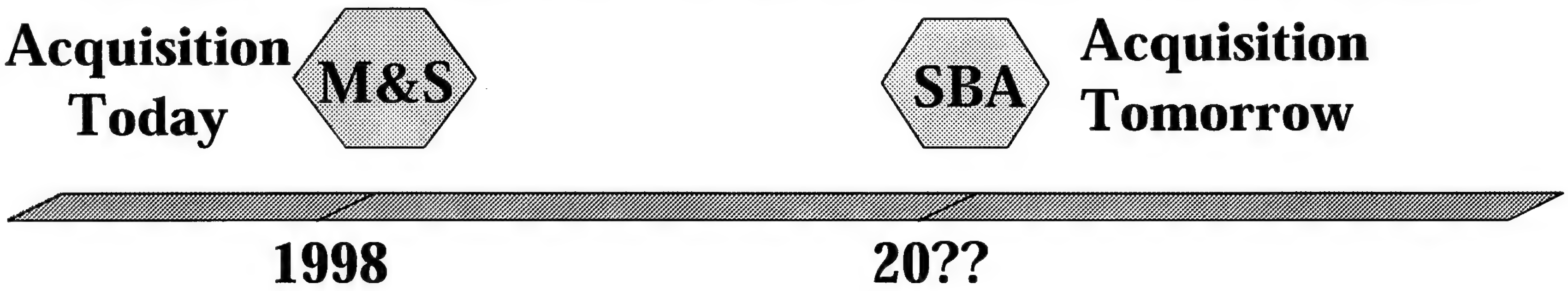
An unprecedented quality of enterprise-wide, collaborative decision making across the acquisition life-cycle...

-- SBA --
Implications

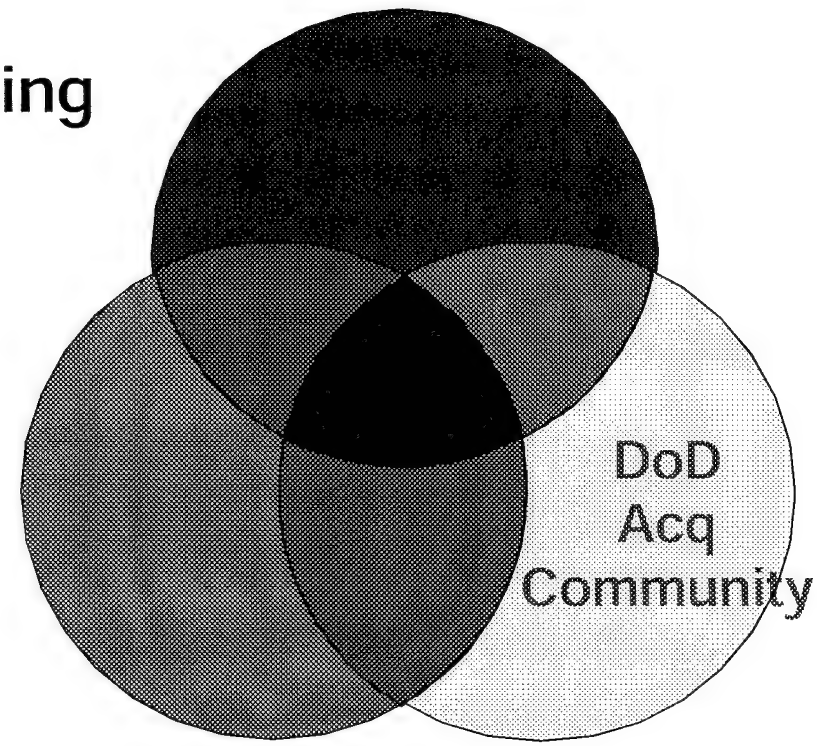
- Implications for Common Technical Framework
  (Our M&S Backbone)
- Implications for DoD 5000 Policy
- Implications for Defense Acquisition University,
  M&S education curriculum,
  acquisition workforce
- Implications for Procurement/Contracting
- ....
- ....
- ....

How?:

SBA -- A Work In Progress

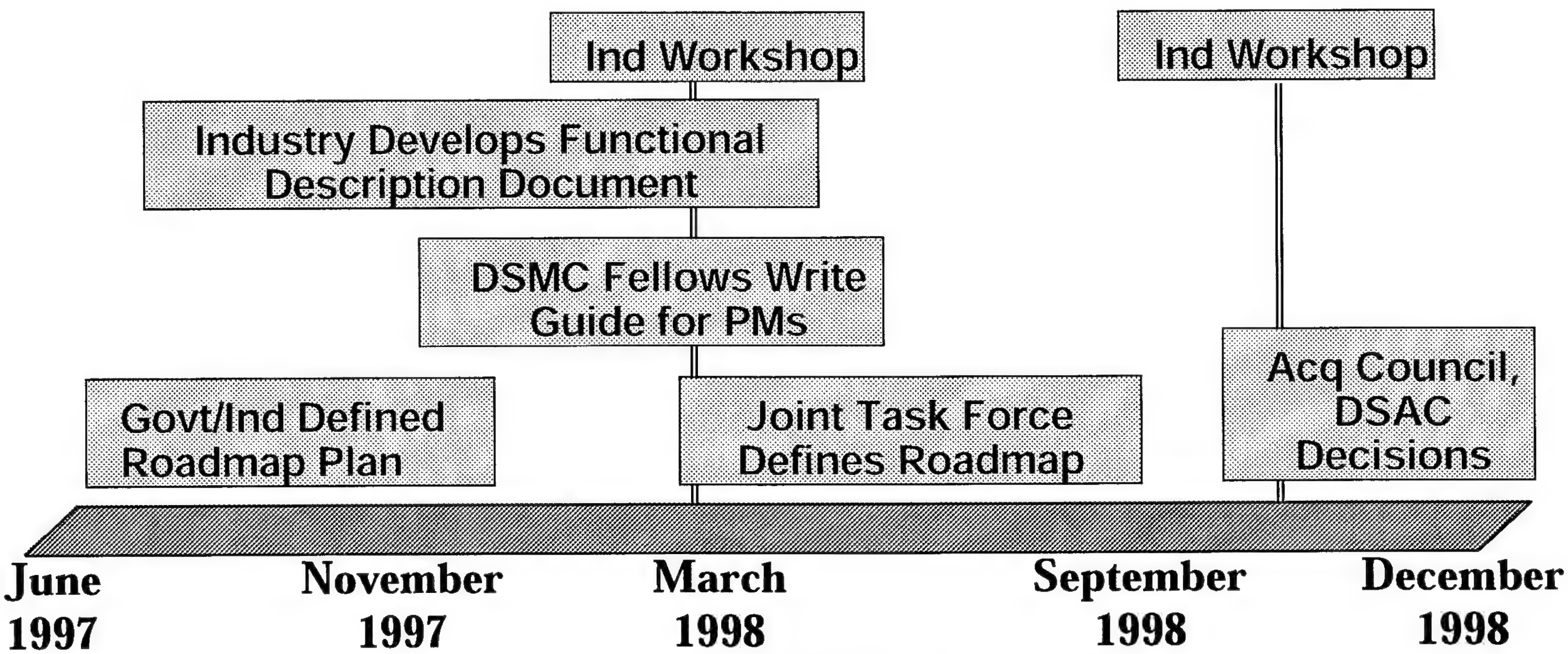


The team making it happen...



How?:

Pathway to SBA



Ongoing Initiatives

- Policy changes for Govt-Ind sharing M&S
- Educational component proposal
- Changes to DoD 5000.2-R (T&E, Acquisition Strategy)
- Defining Pilot programs
- International Action Group on SBA processes (under The Technical Cooperation Program (TTCP) Joint Systems & Analysis (JSA) Group)

How?:

Government - Industry Collaboration

- DoD M&S Acquisition Council initiated a coordinated effort in 1997
- M&S Industry Steering Group offered at the DMSO 1997 Industry Day to work with Government
- Government/Industry group comprised SBA Roadmap Phase I Team, July-November 1997
- Industry sponsored workshop in Orlando, March 17-19, 1998
  - Dr. Gansler keynote speaker
  - Acquisition Council is Executive Panel to receive workshop results
- Second Industry sponsored workshop in Dallas, November 3-5, 1998
  - Check NTSA home page for additional information
- M&S Industry Steering Group (next chart)

SBA Industry Steering Group Members

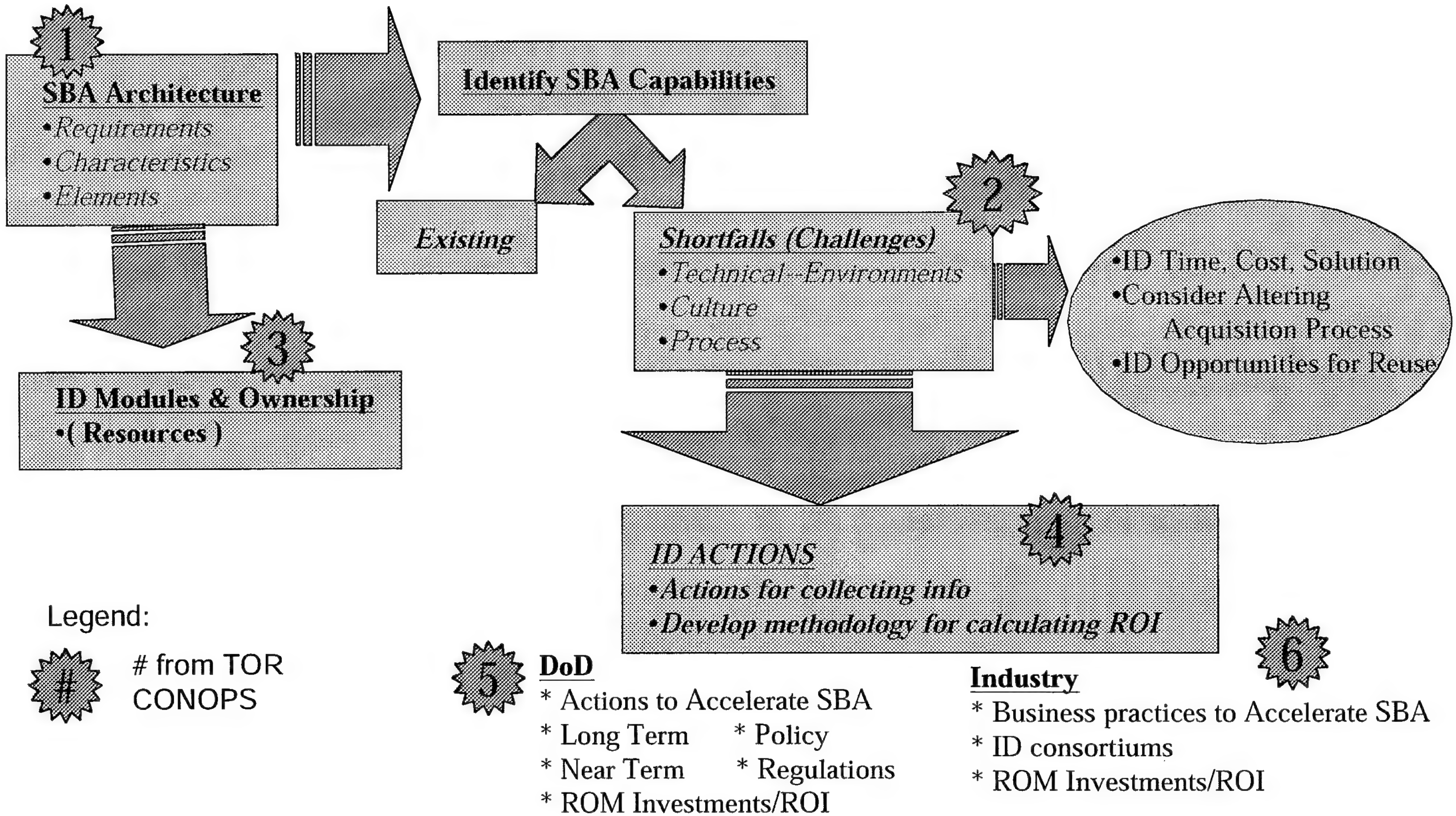
NAME	ORGANIZATION
Jimmy Ajlouny	General Dynamics - Land Systems
Greg Angelini	General Dynamics - Electric Boat
Beau Beauregard	Lockheed Martin
Randy Boys	Raytheon TI
Carl Byers	Original Sim, Inc.
Klaus Danneburg	CACI, Inc Federal
Jan S. Drabczuk	EDS
Gary Engel	McDonnell Douglas
Dick Engwall	RLEngwall & Associates
Tom Ferguson	Dayton Aerospace
Jack Gaudet	Northrop Grumman
Marvin Hammond	MITRE
Ed Haug	University of Iowa
Margaret Herald	Lockheed Martin
Michael Johnson	Boeing Defense & Space
Hal Jones	TASC
Reuben Jones	Boeing Defense & Space
Nick Karangelen	Trident Systems
Mark McLeod	Northrop Grumman
Jim Negro	Draper Laboratory
Jim Nuber	Northrop Grumman
Steve Olson (Chairman)	Raytheon Systems Company
Ted Parker	JTPA
Harry Passmore	McDonnell Douglas
Annie Patenaude	SAIC
Dave Thomen (Vice Chairman)	SAIC
Greg Wilcox	SRI, International
Frank Wysocki	OptiMetrics

How?:

SBA Joint Task Force

- Membership:
  - All Military Departments
  - Office of the Secretary of Defense
  - Defense M&S Office
  - Industry
- Six month effort to define ìSBA Roadmapî
- Terms of Reference approved Feb 17, 1998

Joint SBA Task Force
Overall Flow of Activities



How?:

Recent Actions

- Memorandum on M&S from Dr. Gansler
  - Encourage the use of M&S in Acquisition
  - Emphasizes the need for planning for the use of M&S
  - Endorses SBA initiative
- Strawman policy change for sharing government models with industry, when they are used to evaluate proposals
- Proposed changes to DoD 5000.2-R
  - Acquisition Strategy section
  - Test and Evaluation section

How?:

Recent Actions (Contíd)

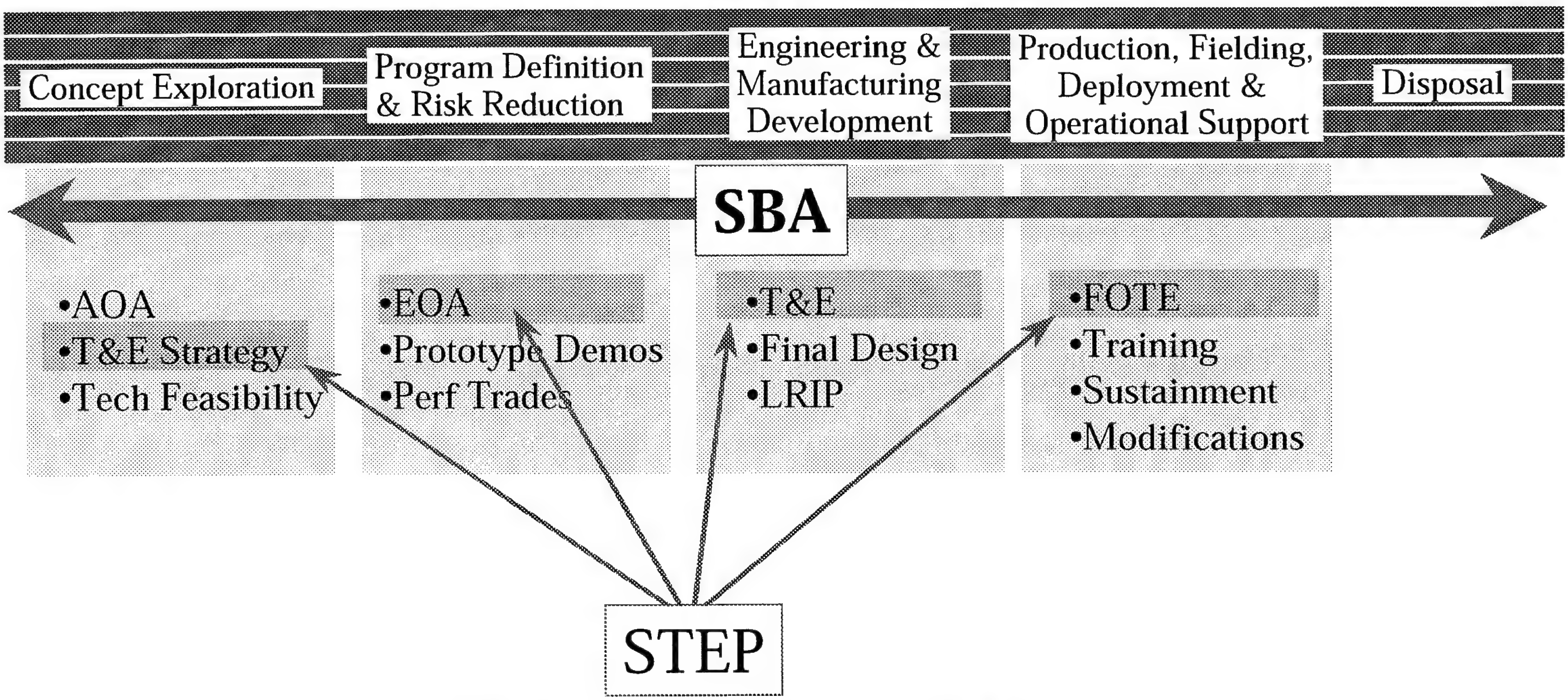
- Defense Systems Management College
  - Three Research Fellows
  - Defining how program managers can implement SBA to revolutionize defense systems acquisition
  - Product will include not only the DSMC book, but also material for the DoD Acquisition Deskbook.
- The Technical Cooperation Program (TTCP) Joint Systems and Analysis (JSA) Action Group (AG-5) established similar vision for SBA
- Advanced Research Projects Agency (ARPA) Digital Knowledge Engineering (DKE) program agreement to collaborate on SBA pilot projects

HOW?:

Simulation, Test and Evaluation Process (STEP)

How?:

SBA & STEP in the System Life Cycle



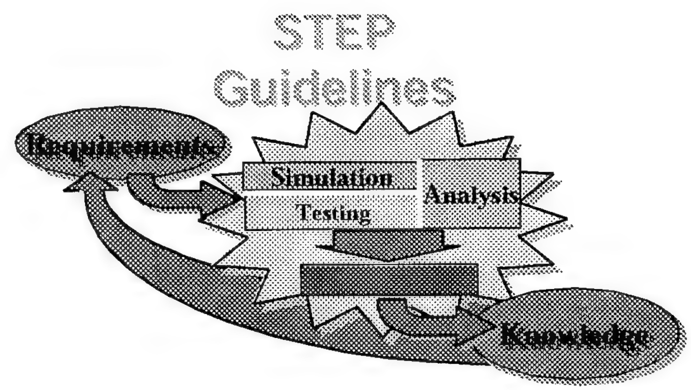
STEP is a sub-process of SBA

How?:

STEP Guidelines

http://www.acq.osd.mil/te/programs/tfr/step.htm

Simulation , Test, and Evaluation Process



December 4, 1997

STEP Guidelines Approval

ACQUISITION AND TECHNOLOGY

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

DEC 31 1997

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
ASSISTANT SECRETARIES OF DEFENSE
GENERAL COUNSEL OF THE DEPARTMENT OF DEFENSE
INSPECTOR GENERAL OF THE DEPARTMENT OF DEFENSE
ASSISTANTS TO THE SECRETARY OF DEFENSE
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Simulation, Test and Evaluation Process

On October 3, 1995, the Department announced that the Simulation, Test and Evaluation Process (STEP) shall be an integral part of our Test and Evaluation Master Plans. The intent was to ensure that simulation and test are integrated for the purpose of interactively evaluating and improving the design, performance, joint military worth, survivability, suitability and effectiveness of systems to be acquired.

Significant progress has been made since that time in refining the STEP concept and producing a set of guidelines that the program manager can refer to. These guidelines are now available on the Web at http://www.acq.osd.mil/te/programs/tfr/step.htm. The benefits derived from applying STEP can only be realized if the whole acquisition community embraces the concept and adopts it as part of the overall process. The ongoing campaign to educate the service acquisition and test communities will bring to the forefront the importance of this initiative and its contribution to acquisition reform.

I am convinced that the proper application of modeling and simulation will result in significant payoffs in program cost savings, cycle time reduction and productivity, and improved mission performance. I encourage each of you to advance and promote this effort as a means to a better way of doing the acquisition business. With STEP as a key evaluation process, the Department will build effective, suitable weapon systems of higher quality with decreases in cost and schedule.

J.S. Gansler

How?:

Leadership Directive

" I am requiring that the Simulation, Test, and Evaluation Process - letís call it STEP - shall be an integral part of our Test and Evaluation Master Plan (TEMPs). This means our underlying approach will be to model first, simulate, then test, and then iterate the test results back into the model."

"Reinventing DoD Test & Evaluation"
Address of The former Under Secretary of Defense for Acquisition and Technology
Honorable Paul G. Kaminski
to the International Test and Evaluation Association Symposium
Huntsville, Alabama
October 3, 1995

How?:

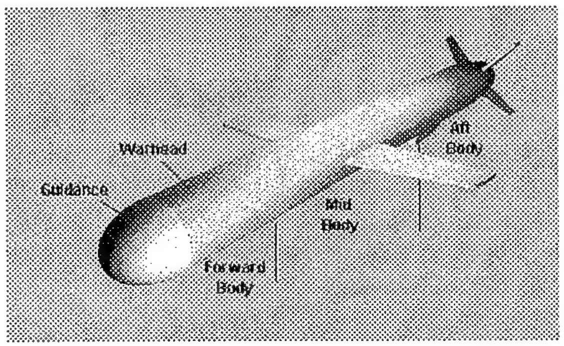
Key Concept

...feed test data back into models so as to continuously improve them over time...

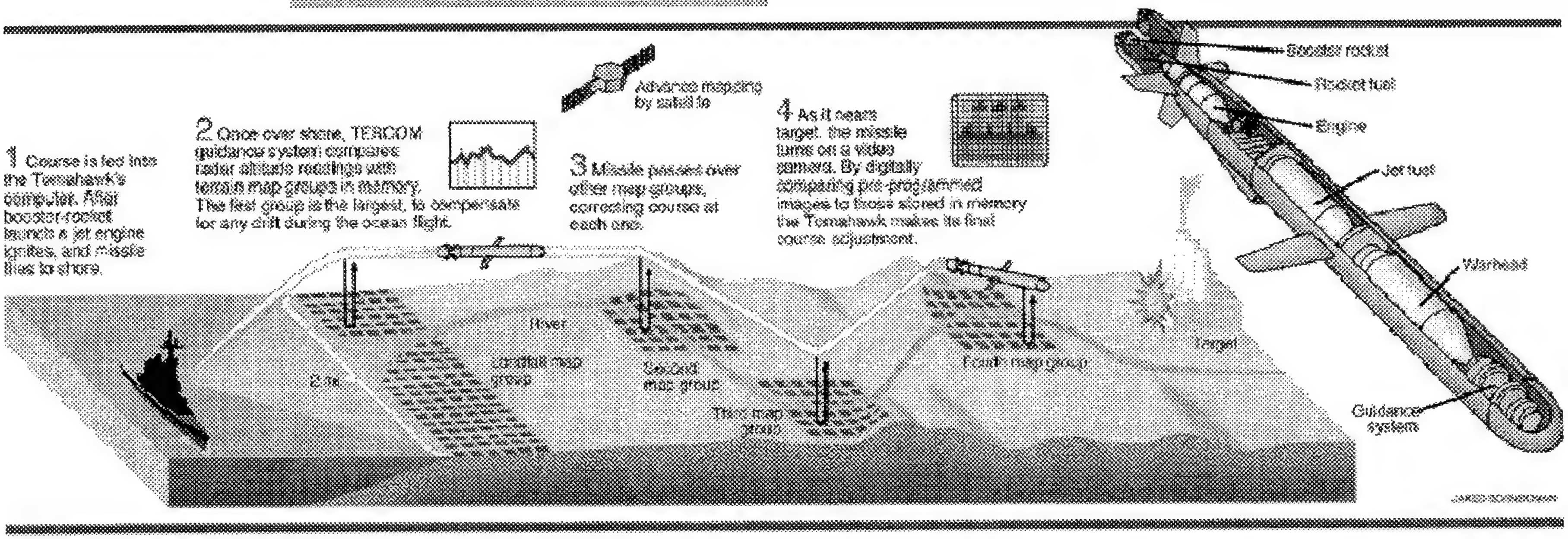
STEP - Strategy

- Re-examine acquisition strategy
  - Is M&S integrated throughout?
- Re-examine test strategy
  - Does TEMP reflect planned use of M&S in testing?
  - Do you have resources to feed test data back into M&S?
  - What is needed to infuse M&S into the T&E process
  - Are you prepared to perform VV&A?

Example



Tomahawk



How STEP Affects Testing

The "Old" Paradigm

1. Test-Fix-Test
2. M&S supports T&E
3. T&E and acquisition separate
4. Test specifications
5. Infers a system that meets specs meets mission needs
6. Event-driven oversight
7. Report problems
8. Test all specifications
9. User unilaterally develops and evaluates requirements
10. DT&E and OT&E independent and sequential

The STEP Paradigm

1. Model-Test-Model
2. M&S integrated with T&E
3. Communities united in IPTs
4. Test addressing performance
5. Understand relationship between performance and requirements
6. Early and continuous insight
7. Prevent and fix problems
8. Focus test in high risk aspects
9. Tester assists in developing requirements trade-space
10. DT&E and OT&E partnership

How?:

Military Services' Activity

- **Army**
  - STEP conference, April 1997
  - Simulation Support Plan Guidelines, May 1997
  - SBA Work Shop, January 1998
  - STEP conference, May 1998
- **Navy**
  - M&S Master Plan, Feb 1997
  - STEP conference, September 1997
  - Acquisition Center of Excellence STEP Conference, June 1998
- **Air Force**
  - Policy: M&S in Support of the AF Acquisition Process, Nov 1997
  - STEP conference, Fall 1998
- **Joint**
  - STEP Guidelines, December 1997
  - SBA Joint Task Force, 1998
  - SBAWork Shop, Mar 1998

An Observation on the SBA Opportunity

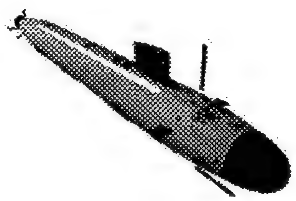
There is Opportunity in Chaos

- The Consolidation of the Defense Industry has left the major players with disparate internal engineering environments, processes and cultures.
- The consolidated companies are now faced with selecting and implementing "common" enterprise practices.
- DoD can capture the moment by convincing industry that SBA should be the core concept of the 21st century company
- This also means that DoD must accelerate the implementation of the SBA vision

SBA & STEP
-- The Bottom Line --

Acquisition costs and cycle times today are too high

Acquisition Today
M&S Within Programs

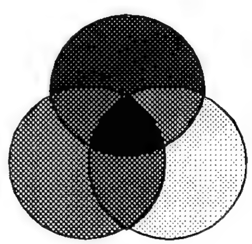


M&S has demonstrated value in systems acquisition

SBA & STEP Visions are agreed

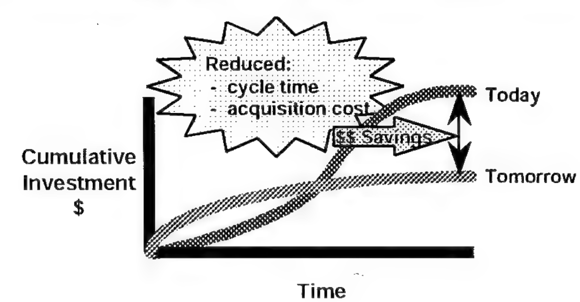
-- SBA VISION --
The DoD and Industry vision is to have an Acquisition Process that is enabled by robust, **collaborative use of simulation technology** that is **integrated across acquisition phases and programs.**

STEP is an iterative process that integrates both simulation and test for the purpose of interactively evaluating



Industry & DoD are defining roadmap & requirements, and beginning to influence the culture to achieve SBA

SBA will enable IPPD to reduce cycle time & cost



Paper Title: **Smoke on The Horizon**

Authors:

Frank E. Montgomery
Gary L. Broxton

Naval Surface Warfare Center
Crane Division

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Naval Surface Warfare Center, Crane Division
300 Highway 361, Code 4024
Crane, Indiana 47522

SMOKE ON THE HORIZON

Authors: Francis Montgomery, Naval Surface Warfare Center, Crane Division

Gary Broxton, Naval Surface Warfare Center, Crane Division

Abstract

The U.S. Navy has not operationally deployed obscurant smoke to hide capital ships from being targeted by enemy gunners for many years. One serious drawback to the use of a smoke cloud to cover a ship is that the obscured ship also cannot accurately target the enemy. However with the sensors and guidance systems of today's anti-ship missiles, the older obscurant clouds represented by fog oil type smoke pots will not be effective to mask a ship from many advanced sensors. With the use of new additives and/or new compositions, missiles' sensors can be blocked from achieving lock onto targets. Smoke deployment of the obscurant where the cloud passes over the ship is not advisable due to the effects on ship sensors, gun/missile defensive systems as well as toxic effects of the smoke cloud on ship's personnel.

Smoke on the horizon will place the obscurant cloud at a distance between the ship and the threatening missile. With the advent of the Navy's cooperative engagement capability (CEC), multiple ship and air sensors' data are distributed throughout a battle fleet by a discrete data link. Engagements are moving from a platform centered logic to a network centered logic. A single ship now has sensor eyes both from its own onboard systems in addition to other sensors from other units of the battle group both in the air and on the surface. Threat data can be automatically integrated and implemented to either spoof the threat or destroy it based on a preset computational decision process. Threat speed, angle of arrival (AOA), time of arrival (TOA), and the situational awareness (SA) of the fleet units positions, speed and direction will be known as the threat data from multiple sensors are integrated. Decision processes will automatically take the most appropriate defensive actions based on continuous updates of the theat's position & heading direction. Smoke will be one component of a two component countermeasure system. The second component would be the decoy, either infrared (IR) or radio frequency (RF). The decoy would be launched to the periphery of the smoke cloud, within the field of view of the missile. With the presence of the ship obscured from the threat missile, only the decoy would be viewed. Even missile seekers with decoy discrimination capability would find it impossible to discriminate the decoy from a ship it could not sense.

INTRODUCTION

Naval capital ships have over the last 40 years traditionally operated in an open ocean, blue water scenario. Conflict with opposing naval forces would occur far from shore defensive forces. Today, littoral warfare envisions U.S. Naval forces much closer to shore to support numerous operations such as amphibious landing and rescue. Battle fleet defense can no longer be completely assured by a 500 mile radius protection zone around the Battle Fleet with fleet aircraft. In some cases, fixed or mobile enemy defense systems could engage Naval ships from shore emplacements or from aircraft that can target Naval vessels soon after launch from enemy airfields. Ship defensive systems may be degraded due to the proximity of land masses on ship targeting sensors or other considerations such as political impacts from launching missiles into busy commercial airways. Decoys on the other hand are comparatively benign to the political environment and if effectively used would provide the protection needed in the littoral zone. The issue this paper addresses is the use of obscurants capable of masking ship signatures in both the infrared (IR) and radio frequency (RF) spectrum and how the obscurants should be integrated into a network centered response. These obscurants combined with RF & IR decoys would provide for a much more effective countermeasure (CM) system than employment of either in a singular mode.

SCOPE OF PAPER

This paper will present a radical concept to naval thinkers. Traditional views of smoke were correct when smoke was employed to hide a vessel as it scurried away from a conflict it wanted to leave safely. However this paper will make the case for the use of smoke/obscurant throughout the course of a conflict. No particular delivery system will be identified as the "one" to use, and this paper will not identify the most appropriate smoke/obscurant compositions. A case will be made to support the concept that the U.S. Navy must begin to seriously study the protection of capital ships with decoys and obscurant systems working in a complimentary fashion. What is discussed is how an inherently platform centered action such as individual ship self-protection can be made more effective through a network centered countermeasure system using an integrated decoy with smoke/obscurant response.

ISSUES OF CURRENT COUNTERMEASURE SYSTEM

Advanced missiles with flare rejection and imager guidance use advanced techniques to locate the target and be able to discriminate the target from its decoys. These missiles use advanced decoy rejection techniques that operate to segregate the ship from the decoy by comparing the IR image of the ship and that of the decoy. Also spacial location of the ship and decoy, spectral characteristics of the ship versus that of the decoy's composition, and other notable differences are used to discriminate the ship from the decoy.

The Phase II Ship Infrared Countermeasure Study conducted by the Naval Research Laboratory[1] listed a number of current missiles operating with imager seekers. By the year 2005, most countries who currently operate anti-shipping missiles will have imager guided missiles. This is critical due to the inherent countermeasure resistance shown by missiles that have imager seekers. With missile lethality advancing, seeker designs are harder to defeat by CM. Dual mode seekers (IR/RF), IR imaging, and RF/MMW designs are being introduced by the arms makers. Smoke/obscurant technology developed for tank protection has demonstrated both IR & RF masking. Certain additives will reflect the electromagnetic return from RF seekers much as chaff decoys do and IR signatures can be blocked. The smoke/obscurant must be positioned between the ship and the incoming threat as shown in figure 1. Even the most advanced seeker with the latest decoy rejection circuitry, would not be able to discriminate a decoy from the missile's intended ship target, if the missile could not sense the ship. The only target in the missile's field-of-view would be the decoy. The missile may not "like" the radiated signal of the decoy, but since the decoy is the only hot, radiating item in the missile's view, it naturally would guide to the decoy.

Another issue exists due to the evolving nature of naval warfare. Network centered warfare has or soon will replace the platform centered approach to fighting battles. Network implies that all weapons, and in this case all countermeasures, are orchestrated by a central entity. This would most likely be a computer loaded with the appropriate written code. It would compile missile approach data, tell the countermeasures/weapon systems when to fire, and follow through to make certain the missile was decoyed or destroyed. This system has its genesis in the cooperative engagement capability (CEC) which has begun its deployment on U.S. vessels. However at this time, U.S. ships that have CEC capability currently are not controlling or influencing the deployment of decoy countermeasures.

One other issue must be addressed before the U.S. Navy can utilize smoke/obscurants as envisioned in this paper. Placement of the smoke/obscurant cloud must be accurate and timely. The current ship CM launcher, Mk-36, is fixed to the deck of the ship. Tube angles of 30 or 60 degrees will place decoys in only those places allowed by the ship/launcher geometry. If different decoy function positions would be needed, the ship would be required to maneuver to a changed heading prior to firing. Also, since the launcher is not stabilized in relationship to the ship, significant ship roll will lock out the launch of decoys until the ship regains a near level attitude.

[1] Phase II Ship Infrared Countermeasure Study, Naval Research Laboratory, Dr. Greg Cowart, April 1998

These issues will be addressed in the concept of operation section of this paper. They will be integrated to show how the use of smokes and obscurant along with the CEC and an improved decoy launcher and cartridges will provide the level of protection U.S. warships will require to accomplish their missions in the littoral arena.

CONCEPT OF OPERATION

The smoke/obscurant is like a catalyst in a chemical formulation. By itself, its presence in the countermeasure equation is only part of the answer. Ship self-protection is enhanced however when the smoke is used in conjunction with ship decoys. It is not by itself, that smoke is made effective in countering anti-shipping missiles. Through the denial of target sensing data to an anti-ship missile, the missile must assume the decoy, which is the only source in its field-of-view, is the intended target. This gives the missile little choice other than to guide on the decoy.

Placement of the smoke/obscurant cloud between the incoming missile and the ship is of critical importance. Also, placement of the decoys in conjunction with the smoke cloud must insure the missile, when decoyed, is seduced away from the ship. The decoy must be positioned such that it is in the missiles field-of-view initially. Ship maneuvers and missile redirection due to ship masking must ultimately direct the missile away from the ship. One important concept that will be enhanced by CEC is the positioning of the decoys to "walk" the missile through a battle group using smoke to obscure the ships while using the decoys to not only redirect the missile from its intended target, but also, to redirect it in such a way that the missile cannot inadvertently reacquire a second ship by accident. One ship decoying a missile away from itself only to direct the missile into a second friendly would not be considered a successful CM experience by the second ship. Through the use of the Navy's CEC system, ships could share sensor data on threats from both surface and air sensors. Also, weapons firing can be accomplished by one ship directing another to launch weapons. The CEC is a secure data link tied to a central computer that shares sensor data as well as weapons coordination.

The CM response for a Battle Group could also be coordinated in such a way. Incoming threat data would be transmitted via secure data link from a P-3 to the Battle Group. Missile trajectory track(s) would indicate the anticipated targeted ship(s) and the time-of-arrival (TOA) of the missile on target. A central computer on the targeted ship would compute the appropriate integrated (network) Battle Group response. Smoke/obscurant munitions would be dispatched to an intercept point 1-2 miles from the ship and deployed. Since the missile's trajectory is known, the missile angle of arrival (AOA) can be computed so that smoke and decoys can be placed at the best location. Ship(s) in the Battle Group at the most adventageous positions would be issued launch orders for smoke and decoys from the targeted ship's computer. Since the Battle Group's formation is known by the computer, each ships' speed and direction of travel, and wind direction and speed are known by the central computer, the situational awareness (SA) of the battle plan for this incident is available.

Figure 1 depicts this incident with the luring of the missile away from the targeted ship. In this simulation of an attack, the targeted ship controlled its destiny by coordinating the response to the missile attack. Any ship in the Battle Group could have coordinated the response. The ships which had the best positions to fire smoke/decoys and those with the best positions to fire weapons to destroy the incoming threat would be automatically qued by the computer on the threatened ship. Orders to launch weapons and/or fire decoys/smoke would be sent via CEC to the Battle Group. This whole command and control sequence could be accomplished in seconds during a real operation.

METHODS OF SMOKE DEPLOYMENT

Figure 2 graphically presents some of the concepts to implement smoke/obscurant in the naval environment. Square 2A of Figure 2 illustrates the use of the 5"/54 naval gun as the deployment weapon system. The projectiles would be the delivery vehicle. Advantages of this deployment system is the rapid delivery time due to the velocity of the projectile and rapid fire capability of the gun. Many pounds of the smoke/obscurant can be placed accurately at the deployment location very quickly. Also, if reseed is needed due to adverse wind conditions, the 5"/54 projectile would be responsive in time and speed. The projectile design is a simple and low technology bullet. The costly guidance package is in the stabilized gun mount and aiming hardware. Since no high cost guidance is needed for the bullet, development costs would also be low since a similar illumination projectile already exists. The new 5"/54 cargo round would be apply suited to integrate smoke compositions into this round at a low cost. Disadvantages are that smoke projectiles must be loaded along with high explosive projectiles in the below deck loading drums. The moment a high explosive round is needed, it is possible that only smoke projectiles are available.

The next square, 2B depicts the use of a trainable CM dispenser capable of launching cartridges of smoke composition and decoys to nearby locations (around 1 mile from the ship). Advantages of this system is the quick reaction time for pre-loaded rounds. Pre-loaded cartridges in the launcher can be fired as quickly as the launcher can be slewed. Also, there are numerous foreign navies with this type system so development costs could be minimized since the launcher and decoys could be bought off the shelf. The disadvantages are that the cartridges once expended must be hand reloaded. Deployment ranges are traditionally short, and other decoys must reside alongside the smoke cartridges which lessens the availability of both munitions.

A corridor smoke round is depicted in square 2C. The round's rocket would be fired from a trainable launcher and a fuze would be preset just prior to launch. The smoke payload would be deployed by the fuze at some preselected point in its flight. This system would need to be larger in volume and weight since all the rocket fuel and payload would be carried by the one round.

This system would need to be developed and would be slightly higher in per unit cost compared to the first two CM systems. There may be an effectiveness payback in that this concept might be programmable to dispense in a smarter manner when compared to projectiles and cartridges that merely detonate to spread their payload.

The last square 2D is the technology leader and would be the most versatile in deployment tactics. It obviously will cost the most and will take the longest to develop. It could be fired from a vertical launch tube and be stored below deck. It would be a stealthy addition to any ship. It would leave its launcher and fly by inertial systems to the exact spot it is needed. Both smoke and decoys would be on board and would be released at the proper moment and location to maximize effectiveness.

IN SUMMARY

Littoral warfare could sometimes preclude the use of some ship defensive systems if collateral civilian or political damage might occur from the use of high explosive weapon systems. If an obscurant is used to mask a ship in conjunction with decoys, the decoys become more effective due the inability of the missile to sense the ship. Smoke/obscurants can be placed between the incoming missile and the targeted ship. The smoke is employed at a distance of 1-2 miles from the ship to insure should the missile continue on toward the ship, its defensive weapons will be brought to bear against the missile.

Title: All you ever wanted to know and less:

EPA issues & Non-toxic Smoke for Warfighter Training

Author: Douglas E. Olson
President, American *Safety &* Health Promotions, Ltd info@buyashp.com

'EPA issues & Non-toxic Smoke for Warfighter Training' focuses on a recent and ongoing 'Case Study' using environmentally friendly, machine-generated smoke to simulate the back-blast of a Surface-to-Air Missile (SAM) Launch. The back-blast is a visual cue to help train the Warfighter aircrew to avoid being struck by a Surface-to Air Missile.

We offer short answers to the following questions:

- What is a Smoky SAM?
- Why is the military looking for visual simulation alternatives for SAM avoidance training?
- How does machine-generated smoke compare to Smoky SAMs as a visual simulation?
- How does machine-generated smoke compare to Smoky SAMs for environmental friendliness, safety, versatility, ease of use, and cost?
- What is the pilot's perspective of having back-blast simulation as a visual cue?
- How does smoke enhance Military Operations in Urban Terrain?
- What are some other applications for environmentally friendly smoke?

EPA issues & Non-toxic Smoke for Warfighter Training

We are excited to share the very positive results of a current and ongoing evaluation using environmentally friendly, machine-generated smoke. This paper focuses on a promising, new back-blast simulation that will provide a visual cue for pilot and aircrew so they can avoid being struck by a Surface-to-Air Missile (S AM).

Background

Surface-to-Air Missiles

A substantial back-blast is a characteristic of the Surface-to-Air Missiles like the (former USSR Military) SA-8 GECKO Low Altitude SAM and the SA-19 GRISOM, a radar command-guided, two-stage SAM. These Surface-to-Air Missiles have a back-blast which is similar to the back-blast of a space shuttle launch, but on a much smaller scale. It is these larger missiles that are the primary concern of our visual simulation.

The smaller Man Portable Air Defense System Missiles (PADS) do not produce as significant a back-blast.

Smoky SAMs

Smoky SAMs (GTR 18) are currently deployed at Electronic Warfare Sites to provide a visual simulation of a Surface-to-Air Missile (SAM) Launch. They work well, functioning in a manner similar to a bottle rocket, and produce almost no back-blast. They make a streaming smoke or condensation trail on their way up to about 1,200 feet above ground level. The body of the missile is made of a Styrofoam-like material.

Problem with Smoky SAMs

Smoky SAMs are NOT available after the current (very short) supply is depleted. This is true within the Commander Naval Air Atlantic (CNAL), which includes the Electronic Warfare Ranges of the Mid-Atlantic Tactical Aircrew Combat Training Systems (TACTS), Marine Corp Air Station (MCAS) Cherry Point, NC.

Smoky SAMs will not be available at CNAL due to budget cuts. Given a choice between real bullets and Styrofoam training missiles, the real bullets were chosen.

General Evaluation Information

An evaluation was conducted on 6 May '98 to determine the suitability of machine-generated smoke to simulate the back-blast of a SAM launch. We worked under clear, sunny skies with temperatures approx. 80 F. Winds were variable, estimated at 3 to 8 knots.

SAM Simulation Usage Profile

Mr. **Larry** Roberson, Mission Coordinator, Litton PRC asked American Safety ASHP to provide a smoke generating system capable of simulating SAMs back-blast ten times per day for fifteen-seconds per simulation, five days per week, four weeks per month, and 12 months per year. Ideally this system would be serviced monthly since that is the normal maintenance cycle for the Electronic Warfare Range.

Based on this usage profile provided, we calculate 2,400 Electronic SAM launch simulations per training Site annually.

Conclusion for SAM Simulation

The initial evaluation proved highly successful. The MDG/TF4 Smoke Generator produced smoke, which was easily visible to rotary wing aircrew. Visibility was very good at 3.5-miles/1,000 ft. and during the flight to 2-miles/500 ft. elevation.

Further analysis yielded many surprising benefits, including greatly minimized environmental impact, increased safety, expanded capability, greater ease of use, and dramatic cost savings.

The recommendation from the Mission Coordinator, Litton PRC is to purchase and install one Th4. Once installed, additional evaluation should be performed for rotary wing and for fixed-wing fast-movers as a replacement for Smoky SAMs. If the system proves viable for all, a follow-on buy for other Electronic Warfare sites is recommended.

Advantages of the TF4 Vs Smoky SAMs

The TF is environmentally much friendlier

Smoky SAMs introduce toxic smoke into the atmosphere. if not retrieved, the Styrofoam rocket becomes garbage scattered around the test site. TF4s introduce NO toxic smoke and NO garbage. The Th4 smoke output is so user friendly... MDG Fog/Smoke Generators are the machines of choice for many Broadway shows. Audience, stage crew and actors all breathe the same top-quality smoke indoors.

The TF provides safer training

Smoky SAMs pose a slight risk during transportation, storage and handling since they are Class "B" explosive. The threat to aircraft and crew of a Styrofoam rocket being drawn into a turbojet engine is unknown, but currently presumed to be slight. Th4s pose NO risk to aircraft and crew and NO risk during transportation, handling or storage.

The TF expands training capability

- Threat Emitters (Electronic Simulations) are often used without any visual cues at all. With the Th System installed, this training can automatically and inexpensively include visual simulation too.
- Many Missions occur in the dark. Currently there is no visual cue for nighttime simulations. With the addition of the optional illumination Rack, (included in the Unitized System price) new realism and effectiveness can be achieved during this important training scenario. The illumination System has not been tested and is not yet completed.

More realistic training can be provided since the Th poses NO risk to the aircraft or crew. Training missions can be safely flown at any level. This will be most helpful in providing visual cues at levels of 250 to 1,000 feet. if Smoky SAMs are in use, as a safety precaution at MCAS Cherry Point they avoid training below 1,000 feet.

At Nellis AFB, training is conducted with Smoky SAMs at any altitude (Earth to God) and care is taken to avoid hitting the aircraft.

The TF is much easier to us.

Smoky SAMs require certain personnel certified to handle this Class "B" explosive. Each Smokey SAM launch requires coordinated manpower effort to accomplish. Th4s are non-explosive and NO special training or license is required for handling. Turn it on and it's in the standby mode within ten minutes. When the site operator "locks-on" and fires an Electronic SAM Simulation, smoke deployment will be an automatic consequence. Maintenance cycles are monthly and can be completed in a half-hour.

The TF dramatically lowers cost

The following figures are based on 200 SAM launch simulations monthly or 2,400 annually.

ITEM	($) SMOKY SAM	($) TF4	
Machine Cost		**15,740.00**	TF4 Unitized System
One-Year Consumables	Missiles 220,800.00	**2,772.00**	Fluid, Gas, Electric
Five-year Cost Overall	1,104,000.00	**29,600.00**	Machine & Consumables
Average Cost per Simulation	92.00	**2A7**	Five-year
Five-year Savings		**1,074,400.00**	with the TF4 Unitized System
Cost Ratio	37	**1**	
BREAKEVEN POINT			
to cover machine cost and one-year consumables		**1 month**	with the TF4 Unitized System
to cover machine cost and five-year consumables		**2 months**	with the TF4 Unitized System

What is the Super Cobra Pilots point of view?

The following are highlights of a June 8, 1998 interview with Capt. Sager, MCAS Cherry Point4 NC.
Capt. Sager is the pilot who flew the May 6, 1998 TF4 evaluation mission.

Q What did you *think* of the suitability of the TF4 smoke for SAM Avoidance Training?
A If multiple ground smokes are employed as well, it might be a problem. If they could use in conjunction w/ Smoky SAMs, it would be ideal.

If this were possible, connect the smoke machine to Threat Emitters so they can get an electronic indication too. If this were possible then it would be an invaluable piece of gear.

The larger system (TF4) worked better (than the MAX 5000). Either would be OK in open terrain. In the trees it may take some time for the smoke to rise up. If we could make thicker smoke, it would be good, especially dealing with the North Carolina haze. *Note: MDC Engineers recommend adjustment oft the TF4 to have approx. 150% greater output than the unit used for this evaluation.*

Q How does the Smoky SAM compare to the TF4 smoke you saw?
A The Smoky SAM shows a condensation trail back toward the launch area which is good... But the back-blast from the machine smoke in the long run is likely to be more .... especially if more portable, the smoke machine would be better than Smoky SAMs would.

Since there is the potential for a Smoky SAM missile to get sucked into the intake, they need to fly at 1,000 feet minimum. But in combat sometimes they use Terrain Masking and fly as low as the nape-of-the-earth... I like getting a visual cue and being able to safety train at any altitude.

Q If you had to choose between Smoky SAM and Th4 smoke with electronic indication for SAM Avoidance Training, which would you prefer?

A It would be scenario dependent. I'd say I'm equal on the two methods. I'd choose the one which is less expensive. I think the machine (TF4) may be even more useful to the fixed-wing fast-movers but (I don't know) - you have to ask them... got to go to a mission briefing.

TF Unitized System

The TP Unitized System is designed to accommodate monthly maintenance cycles for gas and fluid replenishment. The estimated System weight is 200-lbs. and it will occupy less than one cubic meter.

The current configuration for the TF Unitized System includes the following:

- One Th4 Fog/Smoke Generator
- One 5-gallon pressurized tank for "Neutral Fluid"
- Two 20-pound Nitrogen Gas Bottles.
- Two "Spare" 20-pound Nitrogen Gas Bottles for monthly replenishment.
- One "Rack" will provide a platform to unitize all the other elements of the System.
- One illumination Rack. For Nighttime SAM launch simulations. We will provide Orange light for illuminating the smoke for nighttime training operations. We are planning for an all-weather illumination rack that can be easily added to or removed from the TF Unitized System. When connected, this will also function as an automatic consequence of a SAM Simulation.

Obscuration for Military Operations in Urban Terrain (MOUT)

MDG has extensive experience with installing All Weather Th Series smoke generators in MOUT facilities.

On May 6, 1998 we also conducted a successful smoke demonstration at the MOUT facility Camp LeJune, NC.

Lt. Co. Fred Hudson, Marine Expeditionary Force Wing said something similar to the following about the MOUT demonstration.

> ... the MDG smoke system enables us to replicate the environment we expect to face fighting in the city.. billowing smoke trapped inside building and the tight spaces between buildings.
>
> Too often we train in a "clean" environment and it doesn't challenge the Warfighter.
>
> The Th is easy to use, low-cost and weather sturdy.
>
> This will improve the quality of training. We can train with our Forward Looking InfraRed (FLIR) and on-board weapons systems.. this will help show how weapon systems work and what systems look like while shooting blanks. This will raise the anxiety of the combatants and heighten the realism tremendously.

Other Applications for Non-Toxic Smoke Generators

- Emergency Evacuation Training
- Security
- Emergency Ventilation System Testing. The US Coast Guard is currently looking at developing a standard for large passenger vessels and it appears likely that they will choose the MDG machines for this program.

Manufacturer/Dealer: Corporate Overview

Since 1979 MDG Fog Generators, Ltd has consistently manufactured outstanding fog machines. MDG Fog Generators were chosen for this Surface-to-Air missile back-blast simulation for several reasons including:

- Excellent reputation for producing rugged, reliable, effective and efficient smoke generators.
- Ability to produce a high volume (50,000 + Cubic Feet per Mm.) expanded smoke cloud with a single machine.
- The only manufacturer that we have been able to locate that has an 'All weather' machine that can be permanently installed outdoors.

MDG and **American** Safety have partnered on several projects and have a successful and close manufacturer/dealer relationship.

American Safety & Health Promotions, Ltd has been offering quality products, sales and marketing services for 22 years. **American Safety** is the dealer & product specialist for SAM Launch Visual Simulation and Obscuration for MOUT Training Programs. **American Safety** is providing point-of-contact, shared customer service responsibility, coordination for product evaluation, and processing for orders and invoices.

EPA Issues & Non-Toxic Smoke for Warfighter Training

- **Surface to Air Missile (SAM) Avoidance Training**
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- **Other Smoking Application**

Advantages of TF Series permanent installation for MOUT

- **Fast response**
- **Rapid Smoke Dispersal**
- **Increased Safety**
- **Saved man-hours**
- **All weather capable**

Advantages of *TF4 Unitized System* **Vs** *Smoky SAMs*

- **Environmentally much friendly**
- **Provides safer training**
- **Expands training capability**
- **Much easier to use**
- **Dramatically lowers cost**

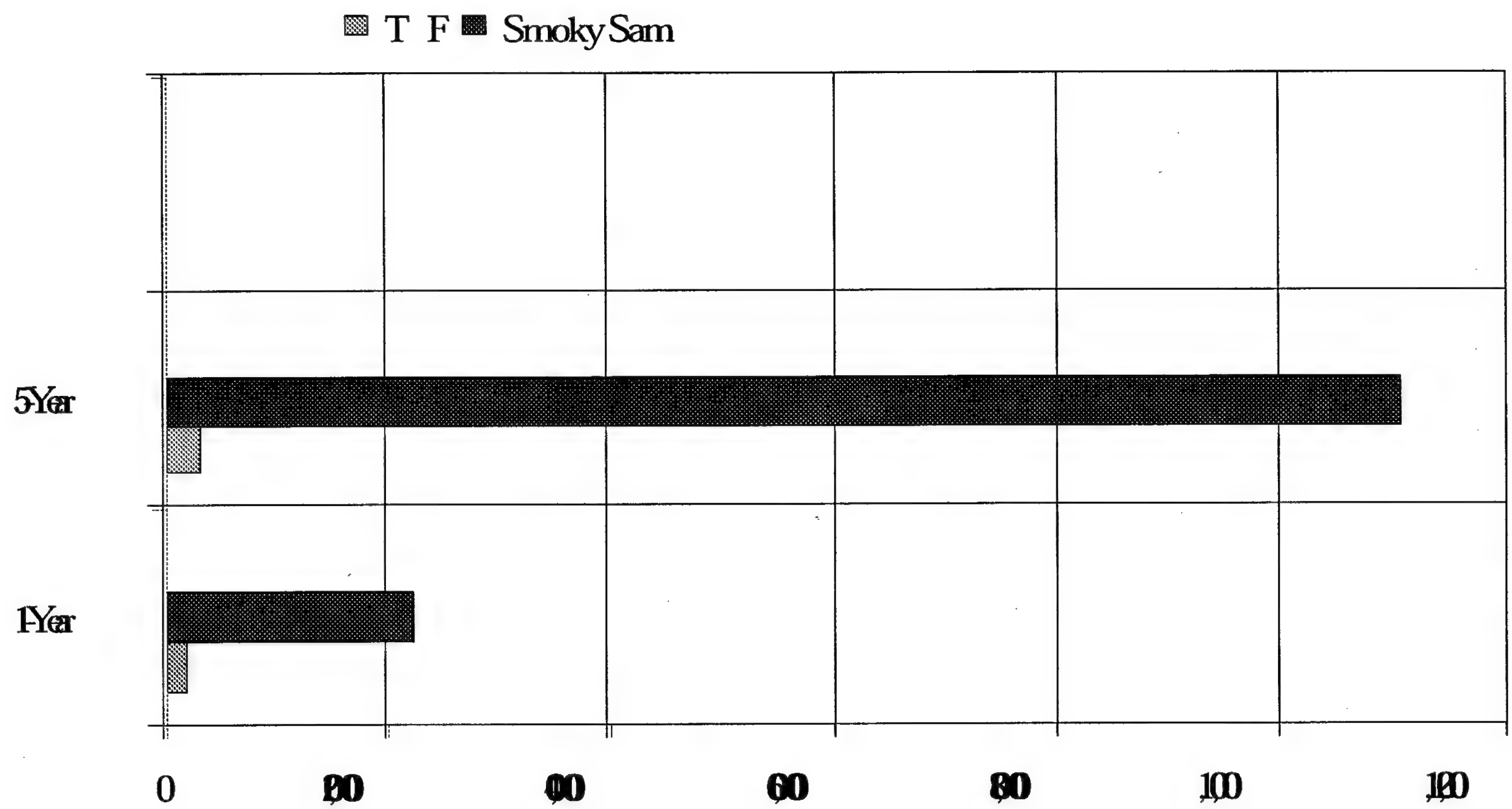
5-Year COST

Based on 2,400 Simulations /Year

TFUnitized System	*Smoky SAMs*
• $29,600 Total	• $1,104,000 Total
• $ 2.47 per Simulation	• $ 92 per Smoky SAM
• Cost Ratio = 1	• to 37
• Savings = $1,174,400	

Based on 2,400 Simulations per year ***1&5-Year Cost***

TF4 Unitized System ***Vs*** *Smoky SAMs*



Atmospheric Support for Ground Systems Hit Avoidance Modeling Effort

Scarlett Ayres, **Robert Sutherland**
U.S. Army Research Laboratory
Survivability Lethality Analysis Directorate
White Sands Missile Range, NM 88002-5501

Abstract

The Army Research Laboratory Survivability Lethality Analysis Directorate (ARL/SLAD) has identified for system analysis studies the need for high fidelity computer simulations of realistic battlefield environments requiring correspondingly high fidelity met/atmospheric input not currently available from conventional databases. The need spans (most) all SLAD mission areas. In August 1997, the Tools, Techniques, and Methodology (TTM) effort "Atmospheric Support for Ground Systems Hit Avoidance" was formed. The purpose of this group was to develop high fidelity meteorological/obscurant models in the FY98 and FY99 timeframe to be used in the missile warning systems models for ground systems survivability studies. These models will be used to develop the capability to predict/simulate effects of obscured atmospheres on propagation of laser beams and missile plume signatures for ground system defensive aids. The overall TTM effort consists of integrating several existing models; the Vehicle Smoke Protection Model (VSPM), the Combined Obscuration for Battlefield Contaminants (COMBIC), the MODerate resolution Transmission code (MODTRAN), and the Missile Flyout Model (FLYOUT), with several models to be developed; the Diurnal Scale Met Characterization Model (DAY24), the Missile Signature Propagation Model (MSPROP), and the Laser Propagation Model (LASPROP). The DAY24 Generator Model will provide the full diurnal-cycle and high-resolution vertical profiles (wind speed, temperature, relative humidity) of critical atmospheric/meteorological parameters for up to 16 stability categories and 22 adverse weather types. LIDAR measurements and met measurements taken via met towers and tetherballoons will be used to develop the model. The obscurant models will be run to compute transmittance and concentration data for selected battlefield munitions. The data will be used to develop an analytical tool for the systems analyst to evaluate the effectiveness of various defensive aids. MSPROP combined with the missile FLYOUT model will take missile signature data and compute the missile signature as seen by a Missile Warning Receiver (MWR) through weather and obscurants. LSPROP will propagate the signal from a laser designator through weather and obscurants to calculate the resultant scattering into a Laser Warning Receiver (LWR).

1. Introduction

Figure 1a presents a flowchart for the TTM effort to propagate a missile signature through the atmosphere, smoke and dust to a MWR. The primary input for this effort is the measured missile plume signature data corrected for the atmospheric losses computed for the site in which the signature data was measured. The purpose of this TTM effort is to calculate how this data would change based upon site-specific met conditions and battlefield obscurants. The

analyst will choose a specific location, time of day, wavelength(s) and pull from a met data base the parameters needed to prime the DAY24 Generator model. The DAY24 Generator model will then produce the vertical profiles of wind speed, temperature, pressure and in some cases aerosol concentration to be fed into MODTRAN, MSPROP and COMBIC/VSPM. MODTRAN will use these vertical met profiles to determine atmospheric losses for the Lines of Sight (LOS) from the tank to the missile. The FLYOUT model is used to compute the position (i.e. LOSs). MSPROP role is to access the FLYOUT model position calculations, access the DAY24 Generator vertical profiles of wind, temperature and pressure and compute the missile plume signature, also, taking into account the atmospheric losses computed by MODTRAN for the site, season and time of day the user has chosen. COMBIC/VSPM is then run for a smoke scenario developed by the user and for the met parameters computed by the DAY24 Generator model to compute the effects of smoke and dust on the LOSs. The modified missile plume signature computed by MSPROP is then further modified by the obscurant degradation computed by COMBIC/VSPM to compute the signal that would enter the MWR. The analyst can feed this modified signature into existing simulations such as Hardware In the Loop (HWIL) simulations or use a MWR model to determine the effects of smoke, dust and the environment on the MWR ability to acquire the missile, determine range to missile, and determine type of missile. This information will drive the selections of the counter-measures (self-defense smoke grenades, IR decoys, jammers, or vehicle movement) to be deployed.

The TTM effort to propagate a laser signal through the atmosphere and obscurants to the LWR is structured fairly similar to the missile plume signature propagation effort. The major difference is a Laser Designator Driver model to compute the laser designator's signal instead of using measured missile plume signature data. The model is capable of providing both the directly transmitted radiation and multiple scattering from all directions inside an obscurant cloud. It computes the interaction of photons with obscurant particles to produce scattering, absorption, and emission. It offers the potential for high fidelity results. Photons could be traced to examine particular aspects of the propagation of a laser designator signal, or the model could be run to compute only those photons that arrive at a certain location such as a LWR aperture. However, the Laser Propagation Model main function is to propagate the laser signal through the atmosphere and through obscurants to a LWR. The effort for fiscal year 98 is to complete a working model for a simple fogoil obscurant.

Another TTM effort that SLAD is developing models the reverse problem of the missile acquiring the target (Anderson, et. al., 1998). These developers are creating a scene based model that will integrate various sub-models together to form a more productive tool to analyze the obscurant impact on a missile's ability to detect a target. Both efforts can eventually be used to as tools to refine Commander Decisions Aids (CDAs). The CDAs will help the commander decided when to use smoke or decoys, when to attack and when to maneuver. Factors driving CDAs are detection range, time to detect, time available to respond, determination of type of missile or laser designator, and countermeasures available.

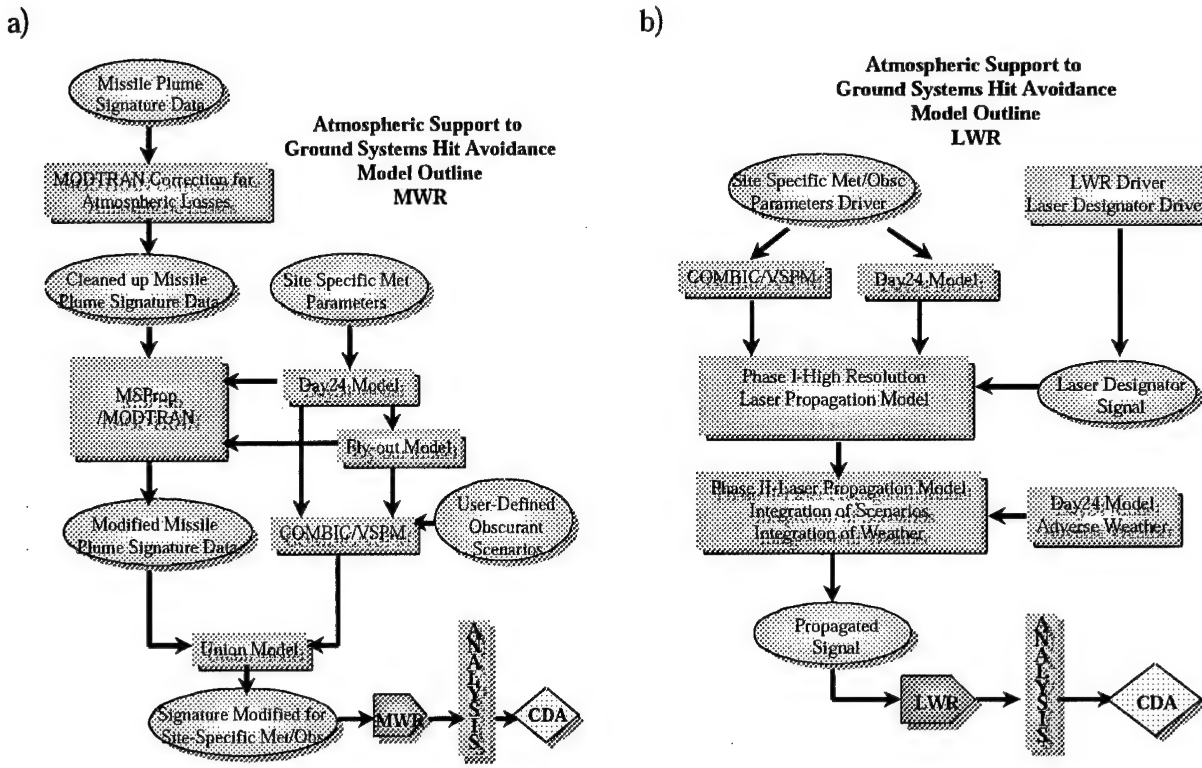


Figure 1a-b Flowchart diagram for a) model to propagate missile plume signature to a MWR and b) model to propagate laser designator signal to LWR.

2. Measurements/Data

Meteorological measurements such as wind speed, temperature and humidity will be intensively collected in the spring, 1998. This data will be used to support the development of the DAY24 Generator model. Site specific met parameters will be determined for four sites of interest by accessing weather databases. DAY24 will read in this data for the four sites and expand the data to create a full-diurnal cycle.

2.1 Meteorological Data

2.1.1 Methodology

LIDAR data and met data will be collected in order to develop the DAY24 Generator model's ability to generate full-diurnal cycle characterization of critical atmospheric/ meteorological parameters. The type of data to be measured is; windspeed, sensible heat flux, mixing height, concentration of aerosols, net radiation, relative humidity, temperature (1 m, 10 m, 38 m), soil temperature (0 cm, 10 cm, 40 cm and 1 meter), and surface temperature. This data will be collected via instrumentation packages attached to towers and with the LIDAR in late spring of 1998 for a month to cover the 16 possible atmospheric stability categories. Surface and profile measurements will be made primarily at sunset, sunrise and midday. Sunset and sunrise are the times when the met parameters experience the most change. Midday is chosen to capture

the "maximum" values of the met parameters. The met data will be used to compute the surface energy balance budget.

2.1.2 LIDAR

The LIDAR transmits laser light, which is scattered off of air molecules, cloud droplets and aerosols in the boundary layer. The returned light is collected in a telescope and focused on a photomultiplier detector and then amplified, digitized, and recorded. The LIDAR can provide water vapor profiles and aerosols profiles and mixing height. A single-wavelength LIDAR system (DRC11-3 YAG laser, 355 nm) will be used to measure the extinction due to absorption (ozone) and scattering (Rayleigh + aerosol). For the slant or vertical path measurement we will be using an upper and lower bound extinction boundary condition given by the LIDAR signal (slope method) and Rayleigh scattering respectively. The laser runs at 10 Hz, and an average of 1000 laser shots is taken. The process lasts about 2 minutes of data gathering. Knowledge of the extinction profile is available within 15 minutes. The receiver and transmitter is near collinear with the crossover occurring at about 200 meters. Vertical resolution is about 1 meter. An example of the extinction profile is shown in Figure 2. Note that the mixing layer height is clearly evident at 4000 meters.

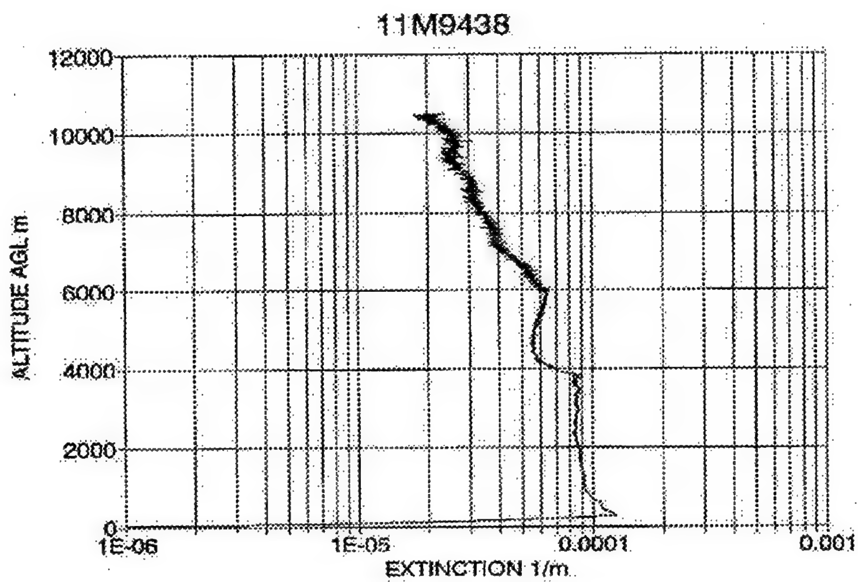


Figure 2 LIDAR data showing extinction vs. altitude for a typical boundary layer atmosphere

2.1.3 Met Instrumentation

Meteorological measurements in support of developing the Day24 Generator model will be collected at the ARL/SLAD Tower site located at White Sands Missile Range (WSMR), NM. The site is located in the Tularosa Basin, southeast of the post area. The elevation of the site is ~1220 m MSL (mean sea level) and is characterized by low desert brush and grasses. Mean and

turbulent meteorological data is collected for several hours in the morning, noon and evening in order to acquire data for all possible atmospheric stabilities. Met data is collected via two sources: one being the standard range support at the range "C" station and the other is specialized local measurements. Met data will be collected at 1 m, 10 m and 25 m. A tethersonde will be used (wind conditions permitting) to collect data up to 1 km. The tetherballon is an aerodynamically shaped helium-filled plastic balloon that is tethered to a winch on the ground. Instead of being blown down-range by the wind, the shape allows it to soar upwards. A met sensor package is suspended a short distance below the balloon on a line different from the tether line. To make measurements at a variety of heights, the winch is used to draw in or feed out more line until the desired height is reached. The balloon is kept at each height of interest for 30 minutes to get a statistically stable sample, before changing its altitude. Also, the balloon can make measurements while it is rising or descending, allowing soundings to be recorded. These balloons are limited to light winds. The tethersonde will be used to acquire temperature, humidity, pressure and windspeed at 200 and 1000 meters. Deployment of other sensor instrumentation is as follows:

- 5103's - Wind Direction and Wind Speed (2 each at 35m, 10m altitude)
- Rotronics(2) - Temperature & Relative Humidity = (2 each at 35m, 10m altitude)
- Thermocouple - Soil Temperature (2 each at surface, and 10cm, 40cm and 1m below surface)
- Infrared Temperature Transducers – Surface Temperature (direct exposed surface & shaded surface)
- Pyronameter - radiation (2m level)
- Air Barometer - pressure (1m level)

The two weatherproof infrared temperature transducers are used to determine net surface radiation. The thermocouples are used to determine the heat transfer at the surface. The towers and tethersonde measurements of temperature, humidity, and wind fluctuations are used to determine fluxes.

2.2 Missile Plume Signature Data

The missile plume signature data was collected at a live-fire test by the Signature Measurements Group of SLAD (Cundiff, 1998). The data were collected with a variety of instrumentation including and infrared (IR) Fourier transform spectrometer (FTS), an IR thermal imaging system, and ultraviolet (UV) grating spectrometer, and a visible-to-near, IR grating spectrometer. The data were reduced as spectral apparent radiant intensity (data not corrected for atmospheric losses) and spectral radiant intensity (data corrected for atmospheric losses (MODTRAN)). Figure 3 shows an example of the missile plume signature data collected for 3-5 μm.

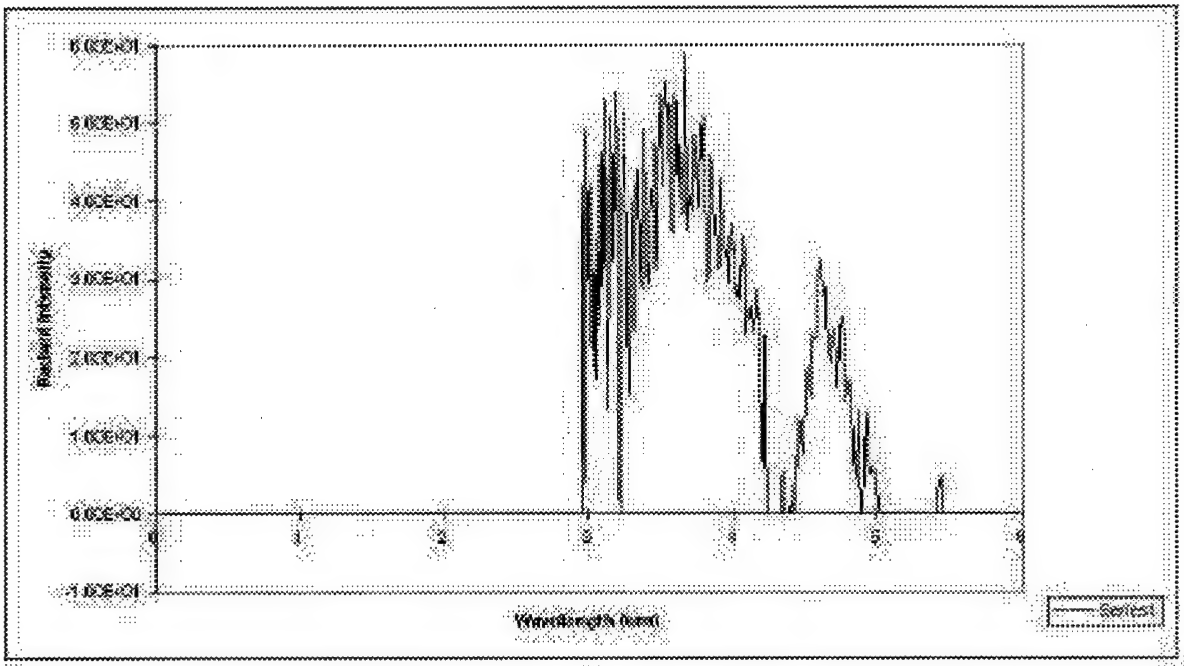


Figure 3 Missile plume signature data

3. Existing Models

3.1 COMBIC/VSPM

The COMBIC (Ayres and DeSutter, 1993) computer simulation predicts spatial and temporal variation in transmission produced by various smoke and dust sources. It models the effects of reduction in transmission by combining the munition characteristics with meteorological information of an idealized real world. COMBIC produces transmission histories at any of seven wavelength bands for a potentially unlimited number of sources and LOS. It also computes concentration length (CL)--the integration of the concentration over the LOS path. Phase I is run off-line to compute cloud histories for each specified munition. Phase II integrates the LOS over all clouds present on the battlefield to determine the CL and transmission. COMBIC uses a simple local area atmospheric boundary layer model where the wind field direction and horizontal windspeed profile are uniform and static everywhere in the scenario. Complex terrain and its effects on windfield is not modeled.

The Vehicle Smoke Protection Model (VSPM) (Johnson and Rouse, 1997) was developed as an augmentation to COMBIC by including certain higher aspects of smoke deployment systems. VSPM explicitly models dischargers locations and orientation on vehicles as well as the orientation of the vehicles on the battlefield to compute grenade locations for input into the COMBIC model. Before, COMBIC users would have to manually compute the location of grenade detonations. These locations are dependent upon the location and orientation of the firing tubes in the discharger, the location and orientation of the discharger on the turret, the location and orientation of the turret

with respect to the hull, and the location and orientation of the hull with respect to the battlefield. In a simulation study, where an analyst might want to simulate the performance of an active defense system, the subtleties of component placement could be important. The augmentation improves the fidelity and resolution of the simulated smoke generation process.

3.2 MODTRAN

MODTRAN is a computer program that calculates the radiance and/or transmission for a specified path through the atmosphere. The transmission calculation use single parameter band models to compute the molecular line absorption of selected atmospheric species. Molecular continuum absorption, molecular scattering, and aerosol absorption and scattering are also included. The radiance calculations consider contributions from atmospheric self-emission, solar and/or lunar radiance single scattered into the path, direct solar irradiance through a slant path to space and multiple scattered solar radiance into path. The atmosphere is treated as a stack of up to 33 atmospheric layers. Physical parameters, ranging from pressure and temperature to molecular absorption and extinction coefficients are defined for each layer. As the path passes through each layer in the model, the atmospheric components of interest are computed and summed over the path and wavelength band. Several standard atmospheres are provided for the user. MODTRAN is used to correct the missile plume data for atmospheric losses that occurred during the missile test. The MODTRAN is used in conjunction with the DAY24 Generator model to account for the atmospheric losses for the user-defined foreign environments. The DAY24 Generator model supplies the necessary physical parameters for the atmospheric layers traveled by the LOS.

3.3 FLYOUT Model

The missile FLYOUT simulation is a full digital fly-out model of a threat antitank guided missile system against a single target (Herold, 1998). The simulation allows a user to input target position and speed along with missile launcher position. The missile is launched when the simulation is started. During the engagement, missile and target data, such as position and velocity, are stored on disk. At the end of the engagement, which is when the missile strikes or flies past the target, the radial and x, y, z miss distance is recorded. Target and missile trajectory data in graphical form can be generated. The engagement environment can be benign or include countermeasures. The modeling of the missile beacon and countermeasure does not include glint or reduction in intensity by obscurants. Future refinements will include modeling the variation in aspect angle of the missile caused by windspeed and direction. Future work will alleviate this problem.

4. Models in Development

4.1 MSPROP

The MSPROP model is the heart of the effort to propagate the missile plume signature from missile to receiver. MSPROP will modify the missile plume signature based upon atmospheric losses calculated for the specific location the user has chosen for engagement. High crosswinds

can increase the aspect angle of the missile. The missile and plume will then be viewed at a slight angle to the direction of flight. MSPROP will not initially compute the effects of these wind-induced changes in the missile's aspect angle on the missile plume signature. The effort for the current year is to enable MSPROP to work for a single threat missile. Future work will improve the model to address wind-induced effects on aspect angle and the effects of clutter. MSPROP will also access MODTRAN to determine the atmospheric losses for the LOSs from the tank to the missile. Atmospheric profiles will be developed this year for four sites of interest. Effects of weather will be included in fiscal year 99.

4.2. Day24 Generator Model

The purposes of the Day24 model is to take the (usually sparse) meteorological data obtained from world-wide climatological data bases and then "fill in" missing data that the user considers critical for their specific mission. In particular, the model can produce a best estimate of a full diurnal weather cycle based upon what data is available (which may include climatological studies from our own sources). The model also produces vertical profiles of parameters such as wind speed, temperature, relative humidity, and in some cases, aerosol concentrations. The vertical profiles begin at the (Earth) surface and extend as high as the mixing level that can vary from as low as about 100 meters at night to as high as 4000 meters during the day. A byproduct of the model is sub-surface temperatures down to a depth of approximately 1-meter into the soil. The model can also be used to drive optical turbulence and electromagnetic (em) clutter models as affected by meteorological variations. The model is semi-empirical and depends upon a good set of input for most accurate results. The model treats only time scales large in comparison to turbulent fluctuations although some turbulent parameters may be estimated from the output. The model is two-dimensional in that it treats time dependence and vertical variations (but not horizontal). The model assumes flat terrain in the immediate vicinity of the measurements and predicts only for the point of the measurements. Plans are in process for including complex terrain and adverse weather in future versions.

The model uses it's own tailored version of the surface energy balance for time evolution and the relatively new transient turbulence theory of transport for vertical profiles. The central feature of the model is the so-named surface energy balance and is illustrated in Figure 4.

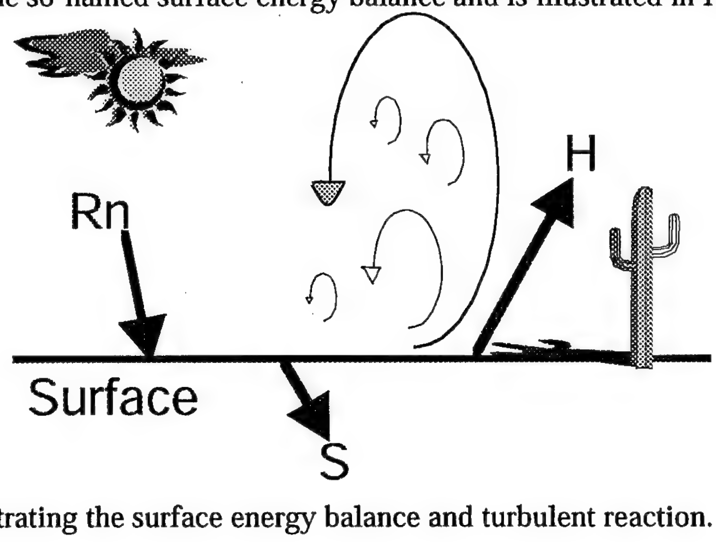


Figure 4 Sketch demonstrating the surface energy balance and turbulent reaction.

In the sketch of Figure 4 the various fluxes are (a) the net Radiative component, Rn, from sun, sky, and surface, (b) modeled air sub-surface heat flux S, and (c) the eddy heat flux, H, driven by the wind and turbulent exchange. If the fluxes balance then there is no change in surface temperature, otherwise the rate of change is governed by the degree of the imbalance. Further details of the mathematical approach can be found in Sutherland et. al, 1994. An example of the model as developed thus far is shown in Figure 5.

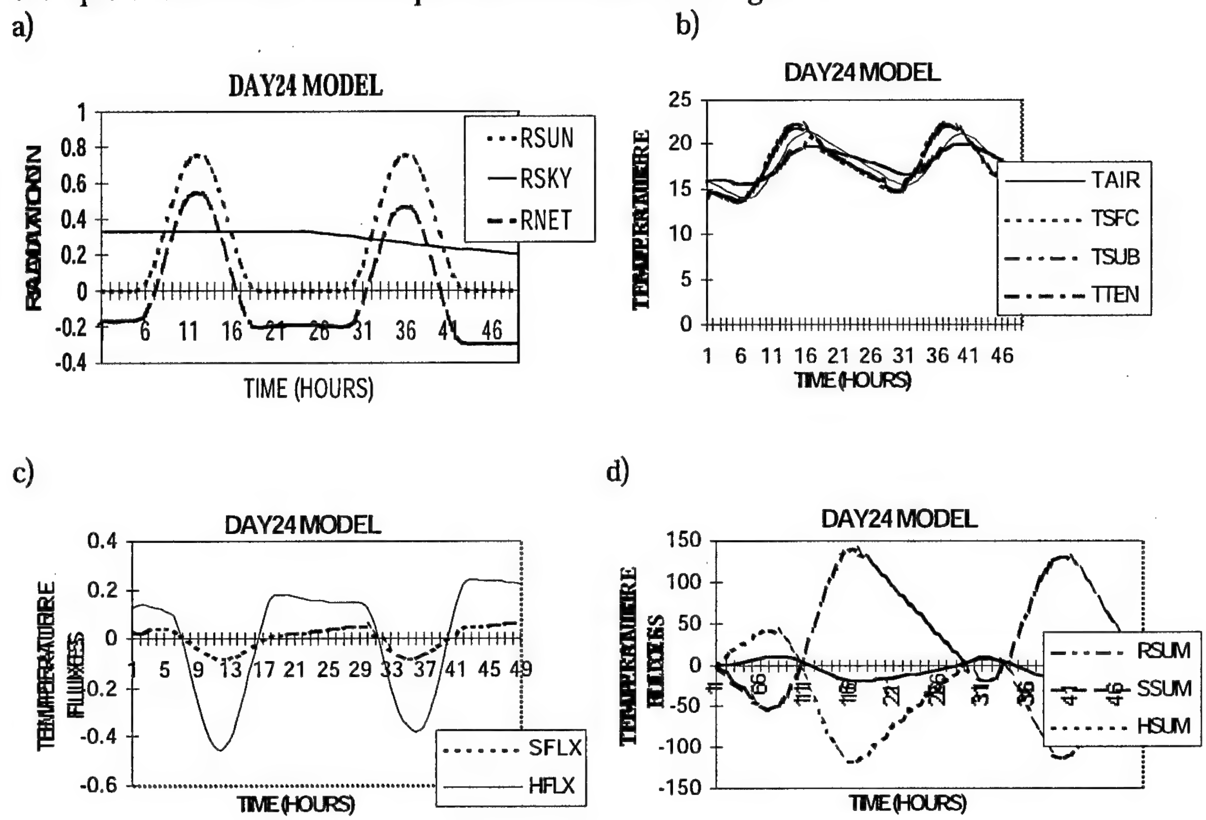


Figure 5a-d Example of DAY24 model showing two consecutive 24 hour periods; (a) driving radiation parameters, (b) air and subsurface temperature reactions, (c) instantaneous surface fluxes, and (d) cumulative surface fluxes.

The radiation (and wind) are the main drivers of the model and are shown in Figure 5a. The values here were made up for illustration to simulate the case of a fair weather day with constant windspeed (not shown) followed by a sharp decrease in wind at midnight and later an increase near midday. The radiation is comprised of the solar component (based upon sun angle and atmospheric attenuation) and the sky component (which is most influenced by cloud cover). For illustration we assumed the sky component to be constant the first day and linearly decreasing the second day. The solar component was modeled the same each day. The reaction as affecting the air and subsurface temperatures are shown in Figure 5b. Note the slow decrease in temperature to a minimum after 5 to 6 hours followed by the sharp increase as the solar component increases, and the subsequent flux changes shown in Figure 5c.

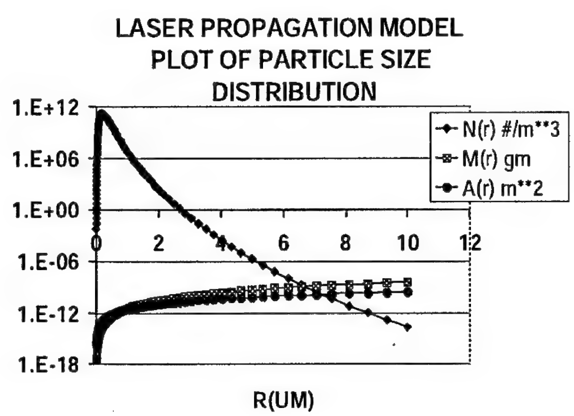
The maximum air temperature is reached after 15 hours and the maximum surface temperature is reached after 14 hours. Note after the end of the first day the overall increase of about 2 degrees for both the air and surface temperatures, indicating a net increase in input

energy. The second day is similar to the first except that the sky component of radiation is allowed to decrease at a constant rate. This is enough to return the final air and surface temperature to their original values of 16 and 14 degrees respectively, indicating a net energy input near zero for the two day period. This is also apparent from the cumulative fluxes shown in Figure 5d which shows a net increase of about 1.16 watts/day after the end of the first 24 hour period but near zero after the full two day cycle.

Our current plans call for further work on the model, the most significant being the further development to the transilient turbulence algorithm to model vertical profiles and the mixing height. With these so determined then other electro-optical parameters, such as the index of refraction structure parameter, C_n^2, optical turbulence can be estimated using techniques developed in Yee et. al., 1993. We also have fieldwork currently underway to verify the model and develop methods for optimizing with best fits to field measurements.

4.3 Laser Propagation Model

The Laser Propagation model is intended as a tool to evaluate laser-warning receivers and laser designator systems as affected by conventional military obscurants such as fog oil. This computer-based model uses ray tracing and Monte Carlo techniques similar to those used in BRLCAD (Butler, and Tannebaum, 1998). The model is capable of providing both the directly transmitted radiation and multiple scattering from all directions inside an obscurant cloud. The model treats the obscurant as a finite array of small volume elements, or voxels, assuming the extinction and scattering properties to be know from first principles optical models. An example of the scattering properties for fog oil is shown in Figure 6a.



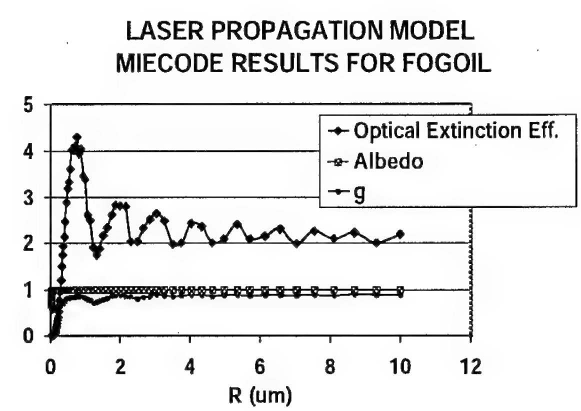


Figure 6. Plot of particle size distribution (a) and corresponding single particle optical properties (b) of fog oil used in the Laser Propagation Model.

The plots in Figure 6 were generated with the ARL model MIECODE (Yee, et. al.) which is based upon the Mie theory of scattering for spherical particles. The curves on the left show the particle number density, N(r), particle mass, m(r), and geometrical cross-section, A(r), as a

function of particle size (radius). Note the peak in the spectrum at about r=0.187 microns, which is very near the geometrical, mean radius, which is 0.215 microns for this case. The results here were generated assuming a log-normal particle size distribution of width σ=1.45 which is typical of measured values for fog oil. The plots on the right were generated with the MIECODE model for a laser wavelength of 1.06 microns and show the optical extinction efficiency, Q_c, albedo, w_o, and phase function asymmetry parameter, g, as a function of particle radius. Note the general monotonic increase in the extinction efficiency at small values of r and the leveling off to a value near 2 at higher r. Note also the fine scale "ripple" characteristic of Mie scattering giving efficiencies as high as 4.29 at r=0.756.

The optical extinction efficiency when multiplied by the geometrical cross-section gives what is conventionally called the optical extinction cross-section which is used in the Laser Propagation Model uses to determine a probability of a photon interaction in the Monte Carlo routine. If the interaction does occur then the albedo determines the probability of either scattering or absorption. If the photon is scattered, then the angle of scattering is determined by the phase function asymmetry parameter using the Henyey-Greenstein formulation. These probability rules are used in a ray-tracing algorithm employing several thousands of photon trajectories to arrive at the total reaching a given point. The model is also time dependent and can address pulse stretching as well as directional scattering. This year the effort is focused on creating a model that can propagate energy through a simple fogoil smoke cloud. Next year the effort will be focused on extending this capability to other obscurants, integration with atmospheric aerosols (i.e. rain, haze, dust) and using scaling techniques to reduce the size of the data base this model creates.

5. Scenarios

Appropriate met observation data will be collected for four sites and categorized according to adverse effects on dominant EM and other sensor systems. Miniature smoke vignettes will be created for the four chosen sites representing both friendly and foreign smokes (where appropriate). MSPROP will be run for the prevalent met conditions at the four sites and for the established smoke in the smoke vignettes. Self-defense smokes like the M76 IR grenades and L8A1 grenades will then be "played". MSPROP will then be run again to determine if these self-defensive smoke grenades will interfere with the MWR ability to track the missile plume. A scenario consisting of only vehicle dust will also be developed. A series of both threat based and survivability suite sensor predictions will be developed based on that data.

6. Summary

The TTM effort entitled "Atmospheric Effects for Ground System Hit Avoidance" will be a useful tool that in conjunction with simulation or software algorithms of MWR and LWR can provide a useful tool in measuring atmospheric and obscurants effects on the warning receivers. These effects in turn can affect the Commander's Decision Aids. The total package, integrating meteorological and systems effects, will offer higher fidelity alternatives for current simulations available to the systems analysis community.

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Target-to-Sensor Vision (Problems, Models, and Analyses)

Robert E. Turner
Obscurants

Abstract: For all applications of electro-optical sensors in the modem battlespace arena it is necessary to consider and account for the presence of the obscuring effects of the atmosphere between the target and the sensor. We provide a brief review of the problems associated with atmospheric conditions when obscurants such as smoke, dust, haze, fog, and precipitation are present, and some of the models and analyses that are used to deal with these problems. Various sensors (ultraviolet, visible, near infrared, and thermal infrared) present different sets of concerns because of the varying wavelength properties of the attenuation of radiation as it propagates through the atmosphere. For certain sensors such as those that operate in the thermal infrared the line-of-sight (LOS) transmission from the target to the sensor is most important, whereas for other sensors, primarily those in the UV, visible, and near-infrared region, the scattering of radiation into the LOS also needs to be considered. Many models have been developed to account for the attenuation of the radiation but there remains the problem of providing sufficient data in the models with near real-time data acquisition for the specific geographic region of interest. Thus, the models may work well in the abstract but not well for the area and time of application. We address these issues to determine what can be done to produce a more comprehensive database for the optical and thermal properties of the obscurants for regional applications anywhere in the world.

1.0 Introduction

In the modern battlespace arena weather plays a role not only in the effect that it has on the mobility of personnel and equipment and general operations but also in the overall performance of sensor systems that are needed for viewing the scene and for target acquisition. Thus, although meteorological data may indicate relatively benign conditions for the transport of personnel and equipment, the so-called "optical weather" may preclude operations because of atmospheric obscurants that exist between the scene and the sensor. It is often the detailed characterization of the optical weather that is important as to whether or not a target can be detected, recognized, or be identified. For an idealistic situation in which no atmospheric obscurants are present and the line of sight (LOS) between the target and sensor contains no solid or liquid matter, the only interference with the transfer of radiation arises as a result of refraction, scattering, and absorption by the atmospheric gases. Turbulence, resulting from thermal motion in the atmosphere can either distort an image or alter the LOS beam of radiation as in the case of the use of a laser to designate a target. In addition, certain atmospheric gaseous (natural and anthropogenic) components can selectively absorb radiation in particular spectral regions as well as scatter radiation into and out of the LOS. These attributes associated with the gaseous component alone can have an adverse effect on the ability of a sensor to acquire, detect, recognize, classify, or identify targets. This effect is, however, even worse in the presence of aerosols and hydrometeors (rain, snow, hail, etc.). These obscurants, characterized by haze, fog, water and ice clouds, smoke, dust, and precipitation can result from natural weather systems or from deliberate action, the latter usually being the case as a countermeasure by opposing forces. The enormous variability in the ability to "see" a target depends upon a number of factors, such as the density of the obscurant, the size distribution of the particles, their composition, and to some extent the shape of the individual particles. In the case of gases, the type, density and temperature can be important. As a result of the variation in the overall composition of the atmosphere between the target and sensor, the visibility can vary from approximately 330 kilometers for an ideal atmosphere with no particulate matter to zero for an extremely dense cloud of smoke or dust, even for short path lengths. The latter is clearly evident to anyone who has been in smoke-filled area.

To account for the detailed properties of the atmospheric obscurants along the LOS is a major problem. In a scientific field experiment it is usually difficult to perform many of the measurements that are necessary to characterize the microphysical properties of these atmospheric particles and gases. In an actual military engagement it is clearly not feasible to perform more than a few, quick, simple measurements at best or to make estimates to ascertain the conditions that define the LOS obscurants. in addition, it is sometimes required that whatever measurements are made, that they be done in a passive rather than active mode. Thus, these requirements can place severe restrictions on the capability of any system, human or otherwise, to determine reasonably accurate values for the parameters associated with the obscurant matter. Another factor to consider is time. Wind and other normal weather effects can quickly alter the behavior of the medium, thereby changing the LOS visibility from one that is a clear condition to one that has nearly zero visibility within seconds. All these attributes, the natural weather the deliberate action on the part of opposing forces in the use of countermeasures, and the inadvertent disturbing effects of the engagement process itself need to be considered in the development of models, sensors, and systems that will be used for military operations. Failure to account for the atmosphere obscurants properly could have a distinctly negative outcome on a particular military action. It should be noted, however, that the optical weather can be beneficial if one has detailed information on the particulate and gaseous components and the quantities on which they depend. If one force has greater knowledge of the

weather conditions than the other, then one may be better able to account for the deleterious effects on sensor performance or be able to deploy additional sensors or countermeasure systems to defeat the action of the opposing force. Regardless of the situation it will certainly be beneficial to have accurate operational models, sensors, or systems in the ever-increasingly technological battlespace of the future.

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Sensors and Radiation

2.1 Sensor spectral ranges

From the earliest times the simplest of all sensors has been the human eye. It is still a remarkable sensor with an ability to perceive the energy of one quantum of light for a dark-adapted eye with a range of illumination of 10. Other sensors have been developed that use the ultraviolet and the infrared portions of the electromagnetic spectrum. Table 1 indicates the general ranges of the spectrum for radiation from the ultraviolet to the infrared. Historically, because of the atmospheric "windows" that fall in the visible and certain parts of the infrared (3.0 μm - 5.0 μm and 8.0 μm - 12.0 μm), these regions were exploited for military sensors. They represent passive sensors that merely

Radiation	Spectral Range	Designation
Vacuum	1 nm – 200 nm	Vacuum ultraviolet
UV-C	200 nm – 280 nm	Far ultraviolet
UV-B	280 nm – 320 nm	Middle ultraviolet
UV-A	320 nm – 400 nm	Near ultraviolet
Visible	400 nm – 750 nm	Human eye
IR-A	750 nm – 1.4 μm	Near infrared
IR-B	1.4 μm - 3.0 μm	Middle infrared
IR-C	3.0 μm - 24 μm	Far infrared

Table 1. Designations of the spectral ranges for electromagnetic radiation from the ultraviolet to the infrared.

detect radiation or scanners and imagers for the display of a scene. More recently, sensors are being used for certain regions in the ultraviolet part of the spectrum. It must be realized that these systems are not only used by ground troops but also by aircraft personnel and by spacecraft for surveillance. Nevertheless, in all cases one must take into consideration the propagation of the radiation from the target or source through the intervening atmosphere to the sensor. Many scenarios can be imagined, such as the use of a laser designator to illuminate a target, the viewing of troops at night with a FLIR, attempting to see targets through dust clouds, or the surveillance of militarily significant areas through atmospheric haze with satellite sensors. For each situation the radiation that propagates

from the target to the sensor will be refracted and attenuated by the atmosphere, the amount of which is determined by the type and concentration of gases and obscurants such as aerosols and precipitation that exist in the region.

2.2 Radiative Processes

To understand the problem associated with sensors detecting radiation through some obscuring medium such as dust or smoke one must consider all components of the radiation that enter the aperture of the sensor. Figure 1 illustrates the basic processes that occur as radiation enters the sensor. Component 1 represents the direct radiation that suffers no loss. Loss of radiation is represented by component 2 which is indicative of radiation that is totally absorbed by the medium, and by component 3 which represents radiation that is scattered out of the instantaneous field of view. Gain of radiation is indicated by component 4 in which radiation that originally propagates in a direction outside the field of view is scattered by the medium into the field of view. Finally, component 5 represents radiation that is either emitted by fluorescence or by thermal emission into the field of view.

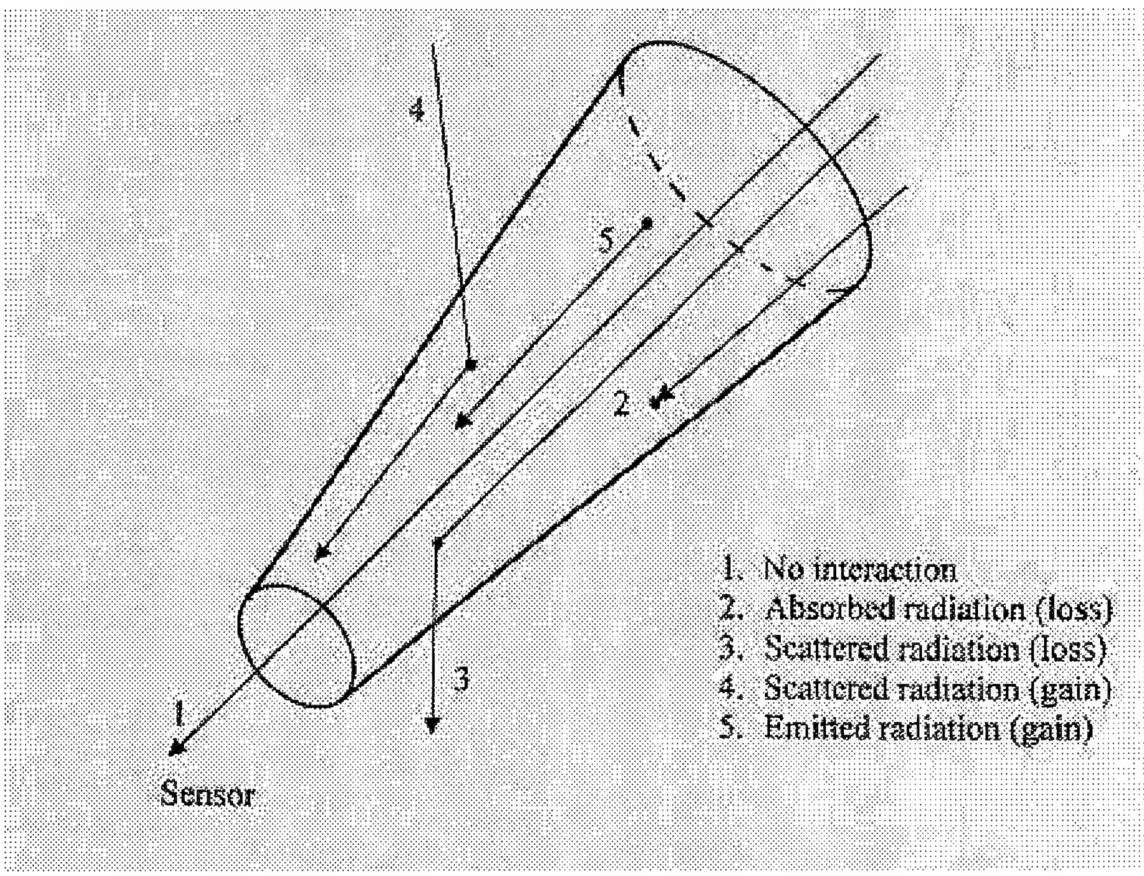

Fig. 1. Illustration of radiometric processes in a scattering, absorbing, emitting medium

The radiometric quantity that is used to describe the radiation that is transferred from a source (e.g., the Sun, Moon, target, or background) through some medium to the aperture of a sensor is called the radiance, i.e., the power density in a specific direction per unit solid angle for a particular wavelength or spectral band. The radiation that enters the sensor can then be represented by the following simple equation:

$$L = L_0 T + P, \tag{1}$$

where L_0 is the radiance reflected or emitted by the target into the field of view and T is the LOS transmittance that attenuates this radiation by absorption and/or the scattering of radiation out of the field of view as represented by components 2 and 3 above. The last term, and usually the one which is the most difficult to account for, is the one that represents radiation scattering into the field of view and/or radiation that is emitted along the field of view as indicated by components 4 and 5 above. It is referred to as the path radiance and represents the multiple scattering of radiation as well as thermal emission. It has an important role to play in the development of models, especially for sensors that operate in the visible and near infrared. It must be noted that the contrast between a target and a background, represented by the simple equation

$$C = \frac{L_t - L_b}{L_b} \tag{2}$$

where L_t is the radiance from the target and L_b is the radiance from the background, can also be written as

$$C = C_0 T_c, \tag{3}$$

where C_0 is the inherent target-background contrast at the target position and T~ is the contrast transmittance. In general, the contrast transmittance can be written as

$$T_c = \frac{L_{bo}}{L_b} T, \tag{4}$$

where T is the usual LOS beam transmittance. Although this is a simple-looking equation, the calculation of the radiances usually involves solving a complicated equation of radiative transfer using correspondingly large and complicated computer codes. This is especially true if the geometry of the medium is complex as in the case of smoke, dust, fogs, or natural clouds. The important point is that if no scattering takes place and if we are dealing with the spectral region where thermal emission is insignificant, then the contrast transmittance is unity and there is no change in the contrast! Thus, even for a strongly absorbing dust or smoke cloud the contrast remains the same as the inherent contrast if no scattering occurs. Unfortunately, for all interactions between radiation and matter some scattering must necessarily occur even if it manifests itself as diffraction. In the thermal infrared such as the 3 - 5 um or the 8 - 12 um regions an image is similar to a visible one of high illumination but of low contrast. Whatever background noise exists,

it is essentially independent of the signal and can easily be accounted for by subtraction as in a FLIR. Such is not the case for the visible or the reflective infrared and the background noise does depend upon the signal level. Thus, we have the complicating effects of path radiance and sky radiance.

3.0 The Obscurants
3.1 Basic Properties

The particulate obscurants in the atmosphere can be represented by their size, shape, and composition. Table 2 indicates the basic physical properties of these particles:

Type	Radii (μm)	Shape	N (cm^{-3})	Composition
Molecules	0.0001	Arbitrary	10^{19}	Atoms
Aitken nuclei	0.008 – 0.1	Irregular	$10^{2} – 10^{5}$	Crystalline
Natural aerosol	0.01 – 1.0	"spherical"	10^{1} - 10^{3}	Salts
Smoke	0.05 – 50	Irregular	10^{2} - 10^{3}	Salts & soot
Dust	0.1 – 200	Irregular	10^{2} - 10^{3}	Minerals
Fog	1.0 – 10.0	Spherical	$10^{1} – 10^{2}$	Water
Cloud	1.0 – 10.0	Spherical	$10^{1} – 10^{2}$	Water
Raindrops	20 – 5000	"spherical"	$10^{-2} – 10^{-5}$	Water

Table 2. Characteristics of atmospheric obscurants

In table 2 the quantity N is the concentration of the particles. One should note that there can be a large difference in the chemical or mineralogical composition of the natural aerosol as well as for dust and smoke particles. Many natural aerosols are composed of materials such as arnmonium sulfate, quartz, hematite, silicate, and soot. Smoke can be generated inadvertently or by deliberate action as in the 1991 Gulf war. In that case the smoke plumes were a combination of soot (black) and salts (white) with various mixtures [1,2]. In the battlefield, smoke can arise from any source such as burning vehicles, buildings, vegetation, or it can arise from deliberate deployment of smoke bombs and generators. Furthermore, the composition varies with geographic location, time of day, and season. For Naval applications, the natural aerosol has essentially three components, each component of which is a fimction of an environmental parameter such as the current or average wind speed. As the wind is primarily responsible for the generation of the aerosol over the ocean, the larger particles are mainly composed of water droplets. It should also be noted that smoke must be considered for naval engagements as well, for example in the burning of ships or aircraft and in the littoral regions where nearby continental sources exist. Dust is also an important obscurant. In the arid region in the middle Bast it was mixed with the smoke in the burning of the Kuwati oil wells. It can also be generated by the movement of troops and materiel, especially when wind is present. Finally, fog and precipitation can occur
and these particles can intermingle with the dust, smoke, and the natural particles to create a complex mixture of aerosols that can seriously reduce the visibility, contrast, and transmittance in the atmosphere.

It must be realized that it is not necessarily the total amount of material along the LOS but, rather, how that material is distributed that determines factors such as the LOS transmission or the visibility. This can be illustrated with the following simple example of viewing a target along a horizontal path 100 meters in length. One should note that

Rain (heavy, 50 mm/hr)	Advection fog
Effective radius ~ 2 mm	Effective radius ~ 5 µm
N ~ 2500 m^{-3}	N ~ 20,000,000 m^{-3}
Water density ~ 2.13 $g\text{-}m^{-3}$	Water density ~ 0.37 $g\text{-}m^{-3}$
LOS mass content ~ 2.13 x 10^{-2} $g\text{-}cm^{-2}$	LOS mass content ~ 3.7 x 10^{-3} $g\text{-}cm^{-2}$
Extinction coefficient ~ 3.32 km^{-1}	Extinction coefficient ~ 27.9 km^{-1}
Optical thickness ~ 0.332	Optical thickness ~ 2.79
LOS Transmission ~ 72%	LOS Transmission ~ 6%
Visibility ~ 1.2 km	Visibility ~ 0.14 km

Table 3. Comparison of the optical (visible region) properties of a heavy rain and a fog for a path length of 100 meters.

although the total water mass along the path in the heavy rain is almost 6 times greater than that of a fog, the LOS transmission and the visibility are much less in a fog. This clearly indicates the significance of the microphysical parameters for aerosols.

3.2 Key (microphysical) parameters

What are the key parameters that distinguish one atmospheric obscurant from another? As indicted in the previous section, the distribution of particle size and composition account for some of the differences. However, for practical applications to military systems there are usually two levels of parameters that need to be considered. First, there are the basic or primary parameters such as, the size distribution of the particles, the complex index of refraction, the shape of the particles, and the number or mass density of a collection. These quantities are, in turn, dependent upon weather related quantities such as the relative humidity and the wind speed, as well as the height above the surface. Thus, for aerosols

Size distribution = F (relative humidity, wind speed, altitude)
Refractive index = F (relative humidity, wind speed, altitude, wavelength)
Refractive index = F (relative humidity, wind speed, altitude, wavelength)

Reasonably good models now exist which can determine the functional behavior in terms of these weather and geometric parameters. For Naval applications, the natural aerosol has essentially three components, a small particle component with an average (mode)components, a small particle component with an average (mode) radius of 0.03 µm, an intermediate sized component with a mode radius of 0.24µm, and a large particle component with a mode radius of 2.0 µm. This is illustrated in Fig. 2.

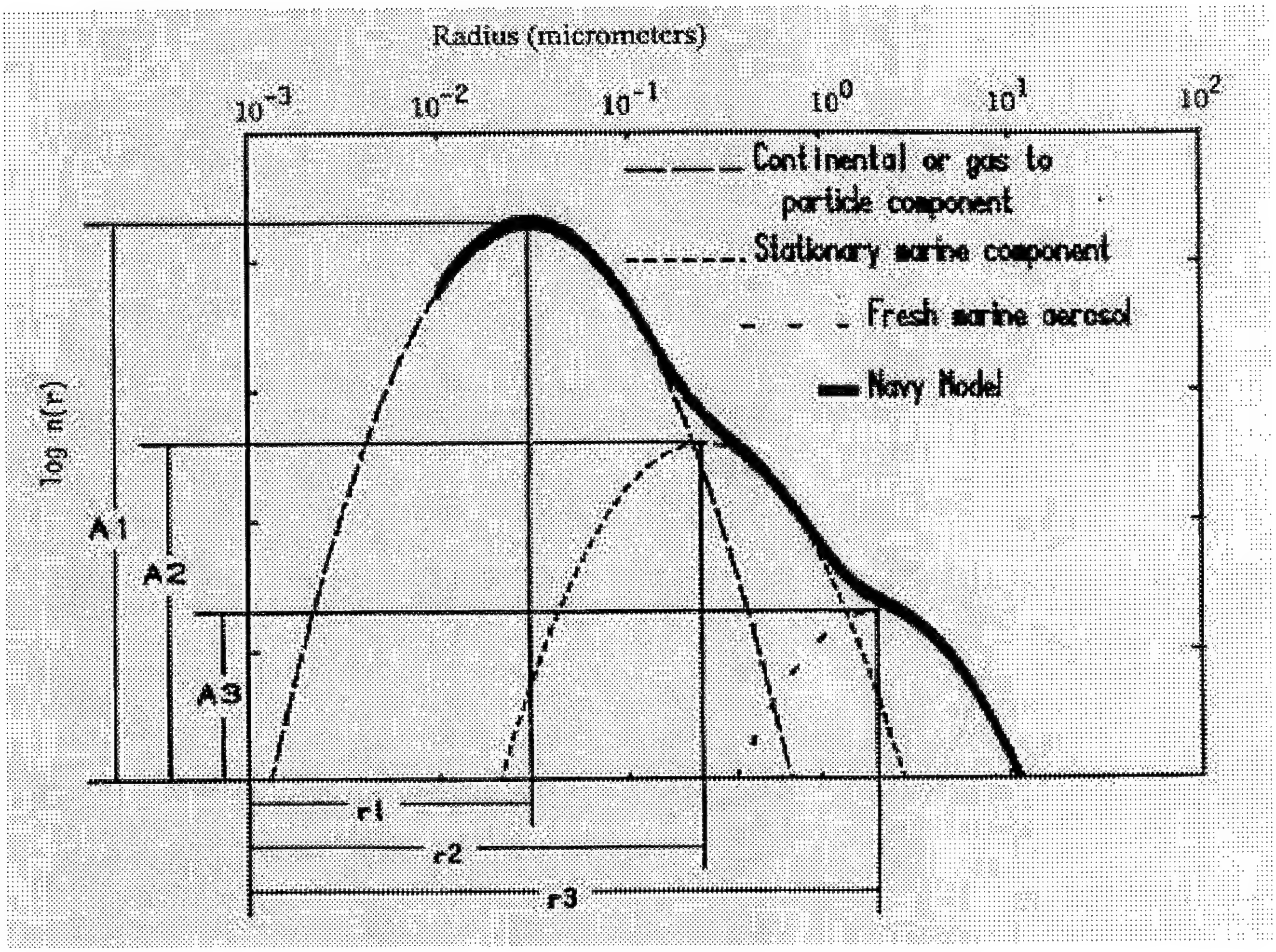

Fig. 2. Navy 3-component aerosol model [3]

The dependence of the shape factor, however, is far more difficult to determine although there are now computer codes [4], which can be used for particles of various shapes. Second, there are quantities that are to be measured or calculated as a result of knowing the values of the primary quantities. These are: the scattering, absorption, and extinction (scattering + absorption) cross sections, the corresponding attenuation coefficients, and the scattering phase function, a quantity that describes the directional properties of the radiation that is scattered from a particle. An important quantity, the single-scattering albedo, is the ratio of the scattering coefficient to the extinction coefficient and essentially determines how much absorption occurs as opposed t(; scattering. It also has an important bearing on the contrast. Thus, one can write these secondary quantities as

α (absorption coeff.) = F (size distr., refr. index, wavelength, no. density, shape)
β (scattering coeff.) = F (size distr., refr. index, wavelength, no. density, shape)
κ (extinction coeff.) = F (size distr., refr. index, wavelength, no. density, shape)
ϖ_o (albedo) = *~lic* = F (size distr., refr. index, wavelength, shape)
p (scattering phase function) = F (size distr., refr. index, wavelength, shape, angle

It is significant that a particle with a cross-sectional area that is almost three times that of another does not necessarily have a cross section that is three times greater. A number of examples of this are given by Kerker [5] for particles with several indices of refraction. In Fig. 3 we illustrate this for radiation with a wavelength of *550* nm incident on a non-absorbing particle with an index of 1.33 and a radius 1 μm, in which the actual cross section is only ~24% greater than that of a particle with a radius of *0.57* μm. The efficiency factor is the actual cross section divided by the geometric cross section. This indicates the importance of the complex index of refraction. For a strongly absorbing particle, such as the one with an index of 1.33- 0.4i, the particle of radius 1 ~m has a cross section that is about three times that of the particle with a radius of 0.57 μm. The sphere with an index of 1.33-1 .5i is not considered to be an absorbing particle although the imaginary part is large. The radiation cannot penetrate the sphere and it is reflective.

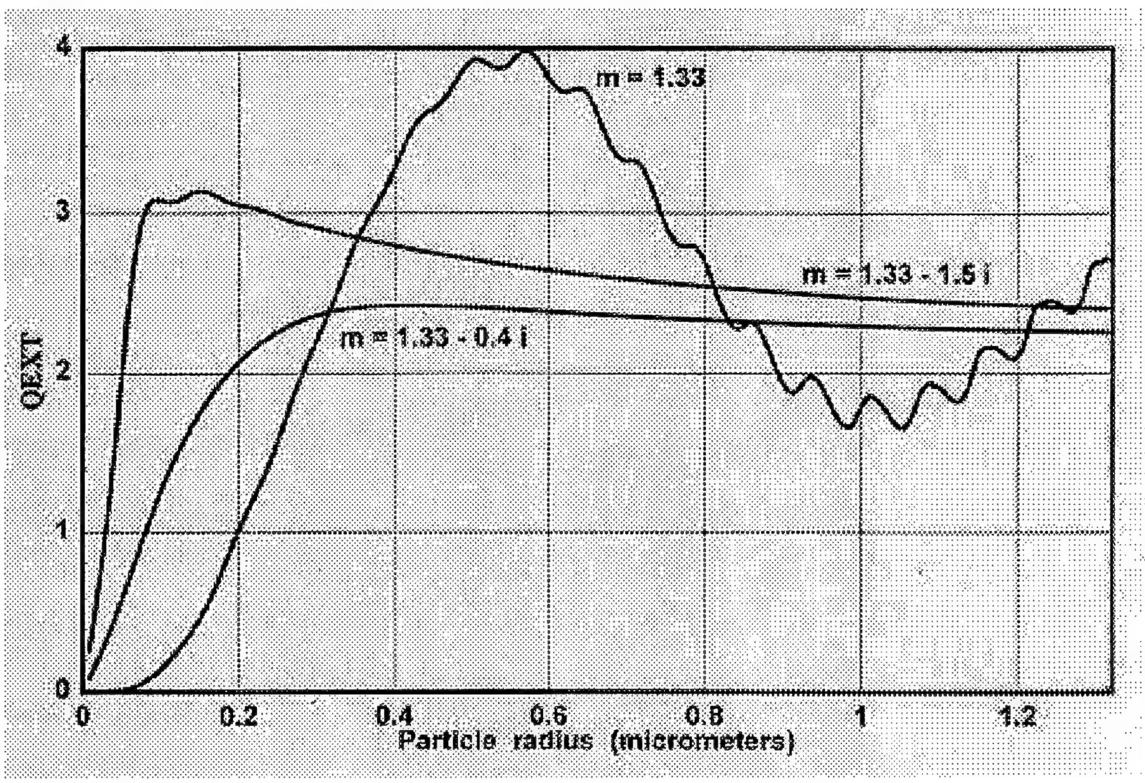

Fig. 3. Extinction efficiency factors for spheres with various indices of refraction

All of these quantities are, of course, implicitly functions of the variables on which the primary quantities depend, such as relative humidity and wind speed. The Air Force at Phillips Laboratory [6] has performed extensive computations on these quantities for use in atmospheric transmission codes. Figure 4 illustrates their calculation of the three attenuation coefficients for a size distribution characteristic of a rural atmosphere with a relative humidity of 50 %.

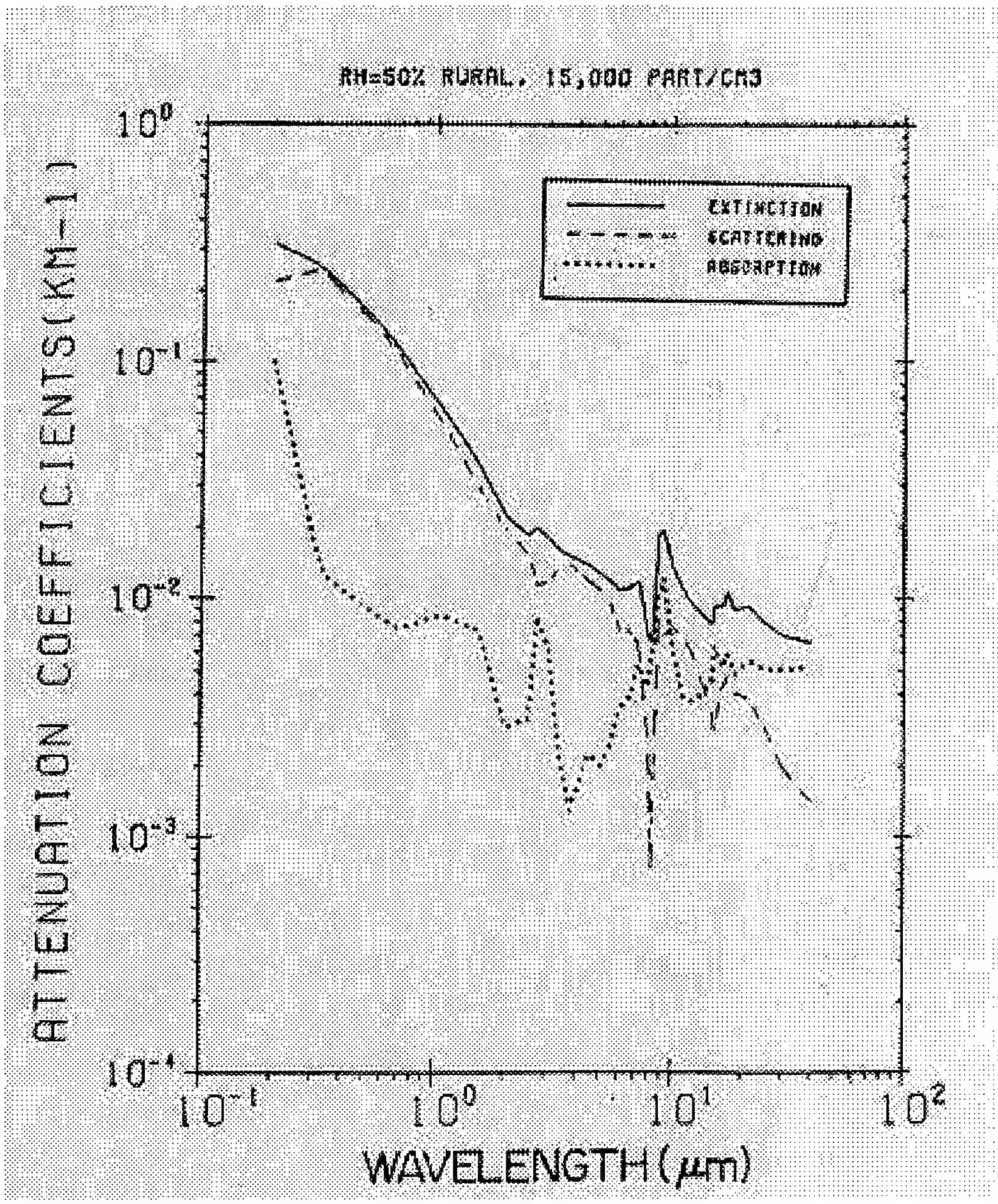

Fig. 4. Attenuation coefficients vs. wavelength for the rural aerosol model at 50% relative humidity.

The dependence of the volume extinction coefficient on the relative humidity is also displayed in Fig. 5. Likewise, Fig. 6 illustrates the single-scattering albedo for the same

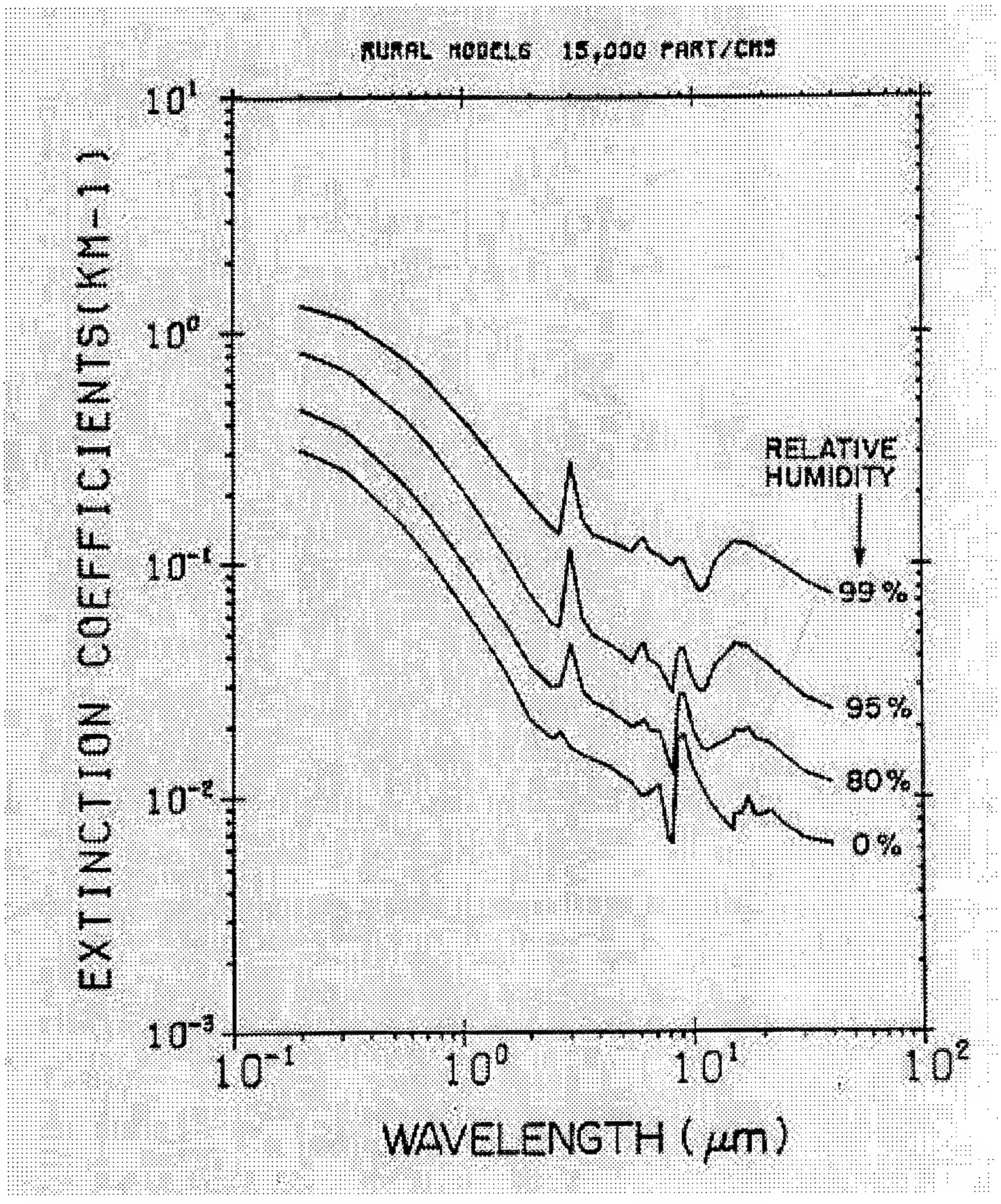

Fig. 5. Extinction coefficients vs. wavelength for the rural aerosol model for different relative humidities and constant number density of particles.

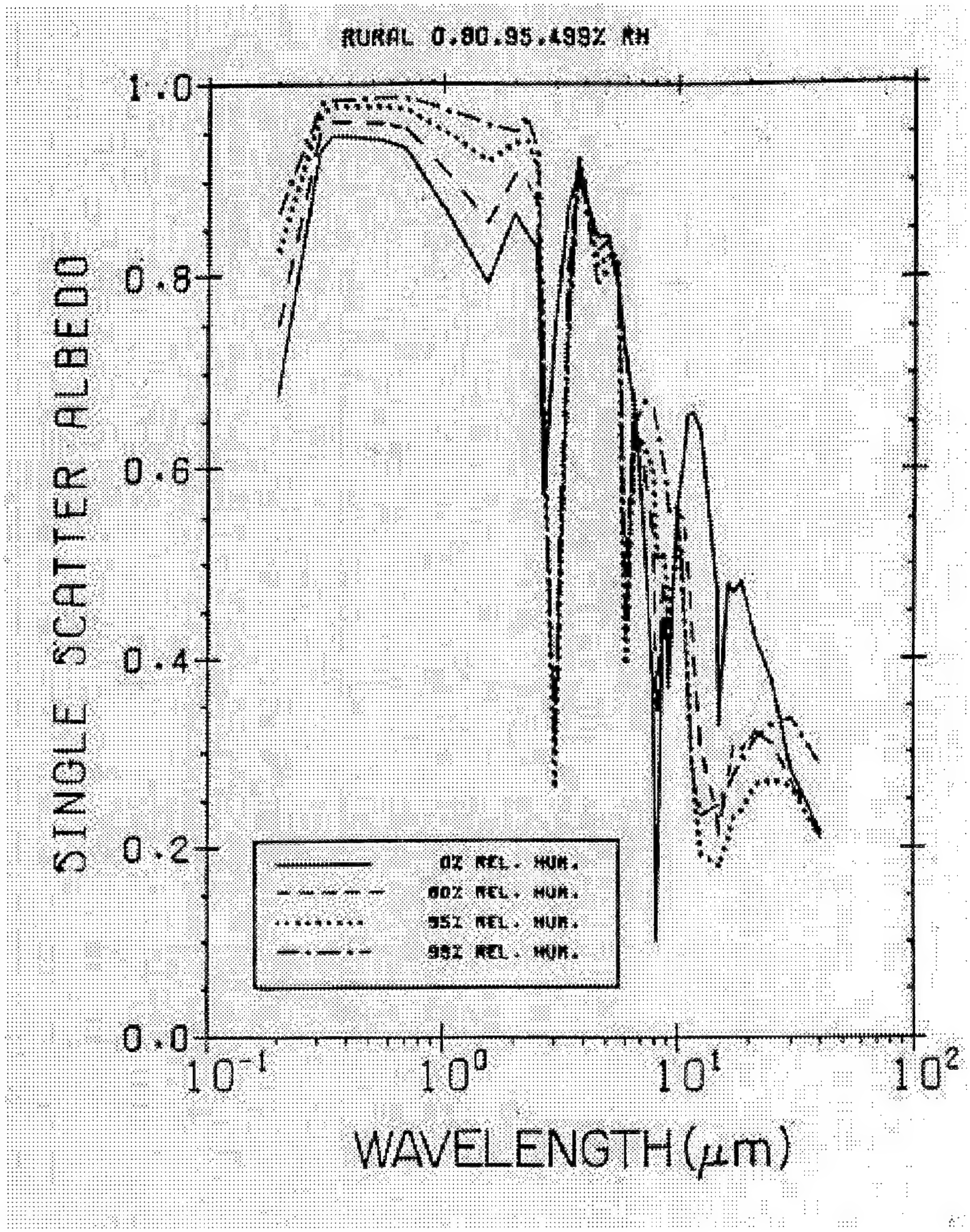

Fig. 6. Single scattering albedo for the rural aerosol model for different relative humidities.

atmosphere and Fig. 7 depicts the scattering phase function for a boundary layer aerosol at a wavelength of 1.06 micrometers for four different atmospheres. It is important to

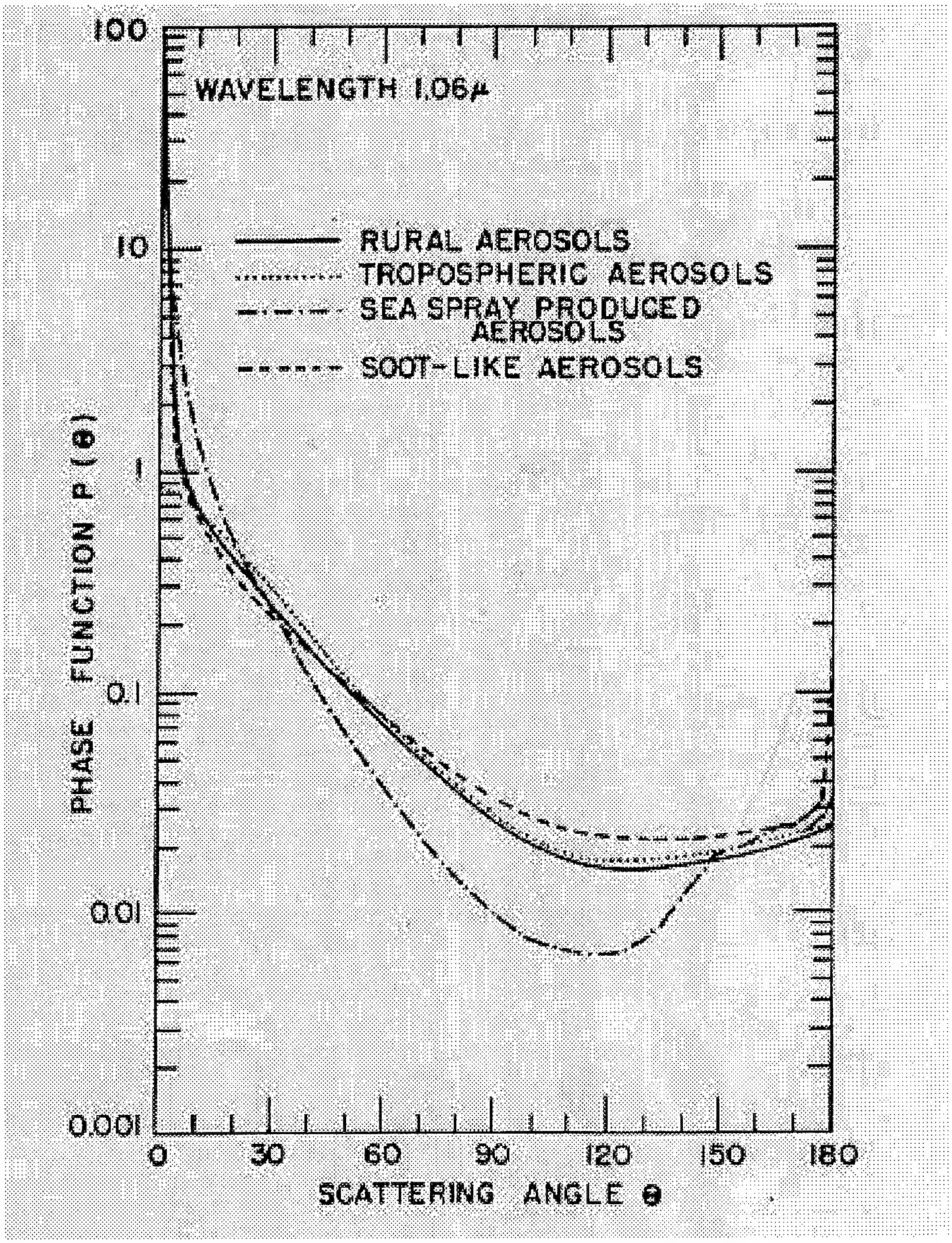

Fig.7. Angular scattering functions of low altitude aerosol models at 1.06 µm.

note that there is a strong dependence on the composition with the rural atmosphere being a mixture of water soluble and dust-like aerosols. The importance of the phase function is clearly indicated. The amount of scattered energy changes by at least a factor of 1000' over the range from 00 (forward scattering) to 1800 (backward scattering). For clouds and fogs it can change by even larger amounts. In general, if the imaginary part of the index of refraction is large (0.2) the amount of absorption will be large, unless it is excessive(e.g. ~10.0) in which case the particle becomes reflective and no longer absorbs the incident radiation. Therefore, the single-scattering albedo is a strong determinant of the amount of absorption. If $\varpi_o = 0$ there is no scattering whereas if $\varpi_o = 1$ there is no absorption.

With the volume attenuation coefficients one can then compute or measure the dimensionless parameter, optical depth. It is the attenuation coefficient integrated over the path of interest and is a function of all the parameters on which the attenuation coefficients depend, as well as the path length. This parameter plays a critical role in the radiative-transfer codes.

Finally, a quantity of considerable importance that can be computed directly from the volume extinction coefficient is the visual range, defined as that distance for which an observer views a target-background contrast. It is given by the formula

$$V \; \frac{3.912}{\kappa} \qquad (5)$$

where κ is the volume extinction coefficient at the Earth's surface at a wavelength of *555* nm. This is the formula for daytime visibility with a contrast of 2%.

4.0 System (operational) Parameters

The final, or system-dependent parameters are those that are used in an operational sense. Having measured or computed the secondary parameters in Section 3.2 one can then use a higher level model to compute the radiometric quantities that are useful for actual operational situations. Examples of these models are LOWTRAN and MODTRAN, computer programs developed by the Air Force [7] which are used to compute the LOS transmittance and the radiance in any spectral band from ~ 0.20 µm to 300 µm for their "standard" atmospheres as well as for a user-defined atmosphere. Figure 8 illustrates a representative output of LOWTRAN. Here one can clearly see the "window" regions of the natural atmosphere. Thus, sensors are designed to operate in the visible, 1.06 µm, 3 - 5 µm, and 8 - 12 µm regions where the transmittance is high. It should be noted, however, that other obscurants such as dust and smoke may affect the performance of sensors in these spectral regions. An example of the computation of radiance in the 3 to *5* µm band as a function of visibility is depicted in Fig. 9. The Army [8], in connection with the BOSAEL (Electro-Optical Systems Atmospheric Effects Library) program during the 1980's produced many practical models for the calculation of radiometric quantities for a large variety of sensors and battlefield conditions. In addition, the Air Force developed an Electro-Optical Tactical Decision Aid (EOTDA) [9] model now being used by the Navy and the Army as well. Most of these "system-level" models will allow a user to input specific meteorological conditions in terms of weather data, as well as sensors, targets, and backgrounds. These models then take into consideration the algorithms and data from the secondary models and/or data and compute the radiometric components for multiply-scattered radiation in the presence of

any obscurant material. Thus, at some

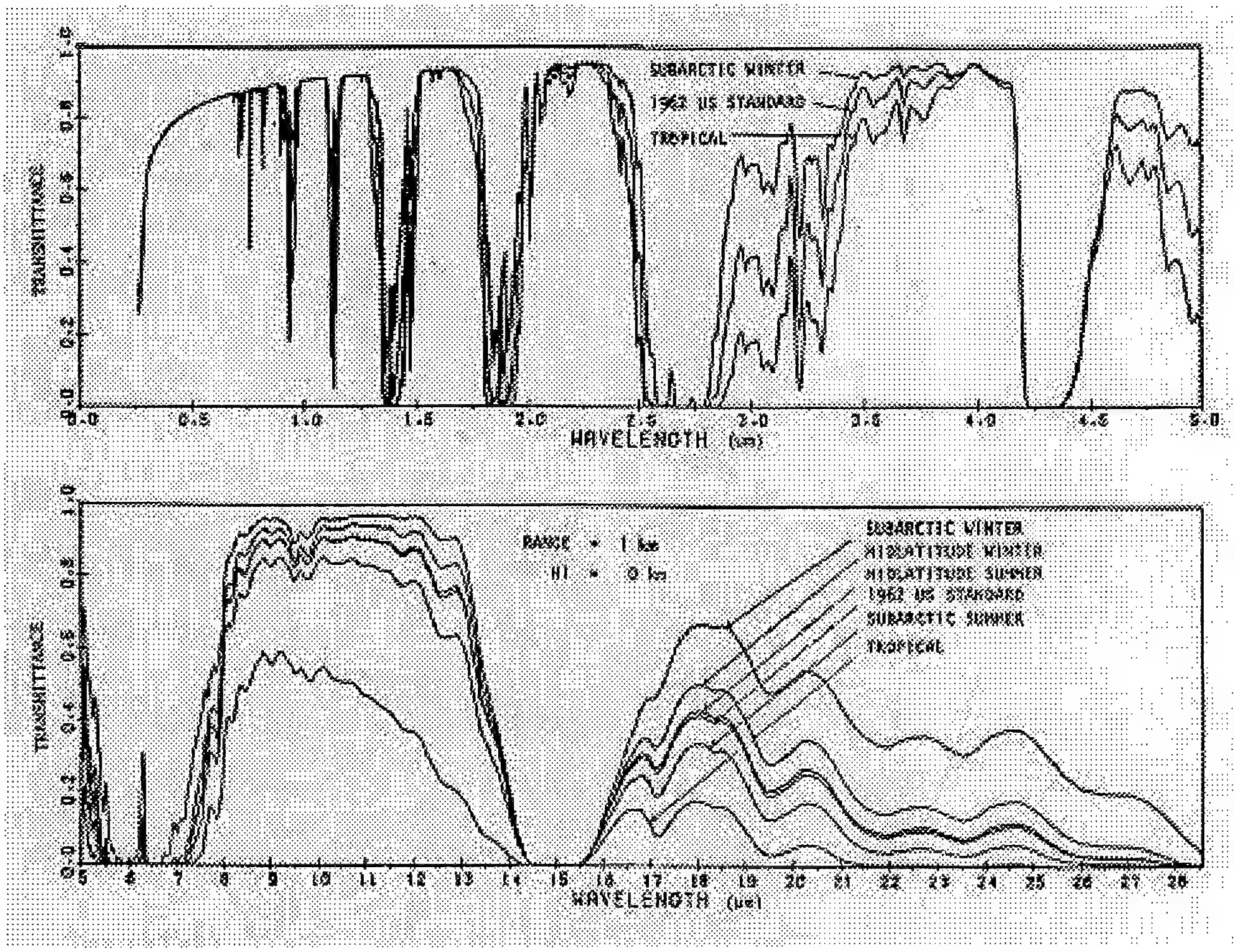

Fig. 8. Atmospheric transmittance for a 1 km path at sea level for six model atmospheres

intermediate stage in these high-level models the functional dependencies may be:

Transmittance = F (Met. Data, geometry, wavelength, operations)
Radiance = F (Met. Data, geometry, wavelength, targets & bkgds., operations)
Contrast = F (Met. Data, geometry, wavelength, targets & bkgds., operations)

where by operations is meant those actions that can affect the nature of the obscurants, such as vehicular motion or live fire.

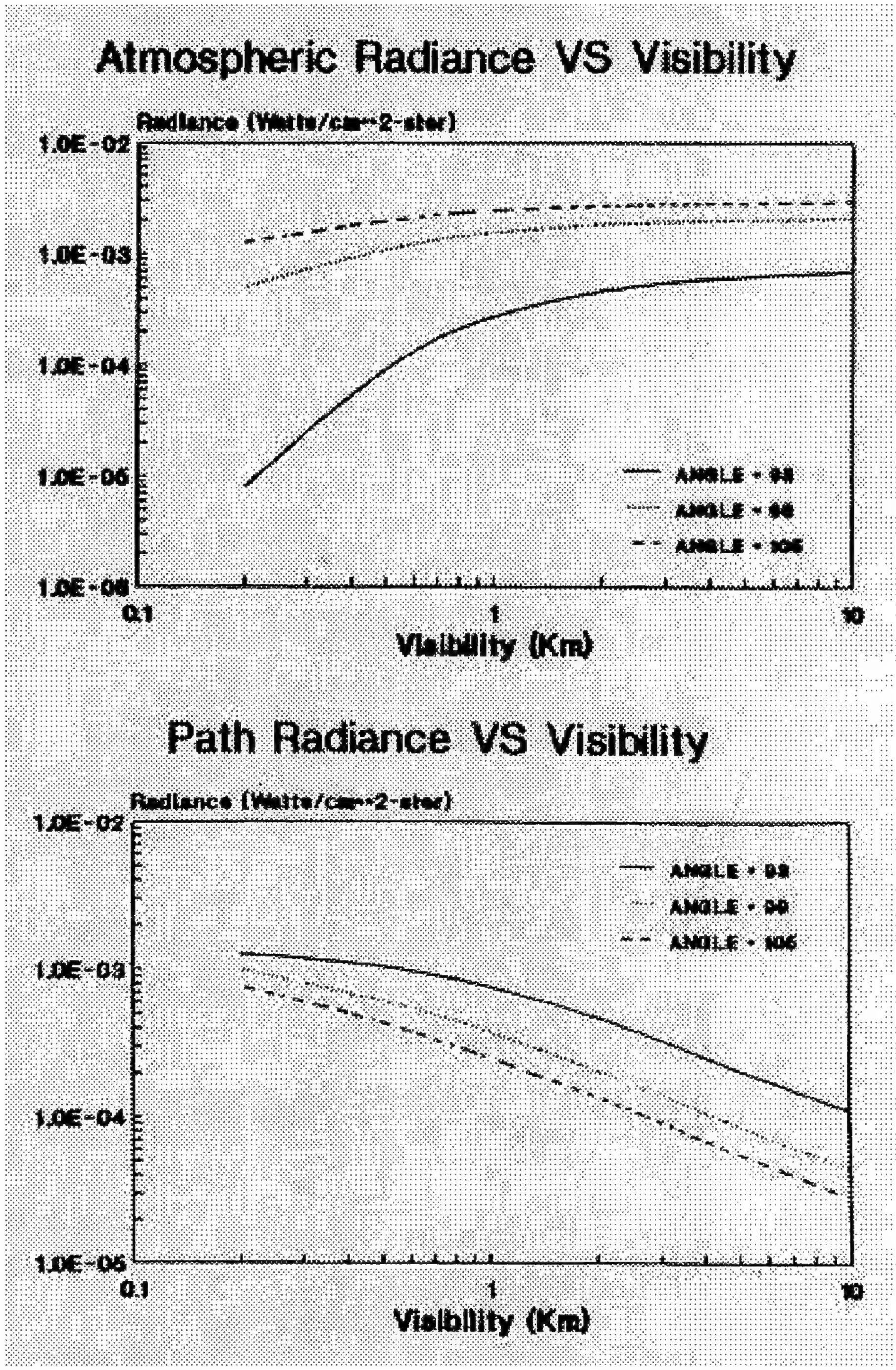

Fig. 9. Radiance components in the 3 - 5 μm wavelength band according to LOWTRAN. Observer altitude = 1 km, target altitude = 0 km, solar zenith angle = 45^0, relative azimuth angle = 0^0, observer zenith angle = 93^0, 99^0 105^0. Midlatitude summer, tropospheric model. Ground temperature =295 K and the emissivity =0.9

Finally, the functional dependency of the operational models can be indicated as follows:

LOS visibility = F (Met. Data, operations)
Minimum Detectable Temp. = F (Transmittance, Radiance)
Minimum Resolvable Temp. = F (Transmittance, Radiance)
Lock-on-range = F (Transmittance, Radiance)

5.0 Model Uncertainties

Where do the greatest uncertainties lie in both the models and in the measurement of the key parameters for an "complete" operational system-level model? Let us consider four levels of systems as are illustrated in Fig. 10. It must be realized that insofar as atmospheric obscurants are concerned, there will be certain tradeoff factors to be considered in the determination of those parameters for which critical decisions need to be made. In the Research Model 1 there is a completely controlled condition in which one can specify the particle size, composition, and environmental parameters. There is a high degree of knowledge of the parameters in this limited system but there is a lack of versatility in the representation of a realistic environment. In a field experiment as in the Research Model 2 there is some control of conditions (e.g., selection of time of day or location) and some knowledge of the data as obtained from the measurements. Also, there is now a more realistic environmental condition with the uncertainties associated with the natural weather. In the Operational Model 1 there is a passive military environment (e.g., surveillance) with little or no control over the conditions, limited knowledge of the system parameters and perhaps a time constraint. Nevertheless, this does represent a much more realistic environment. Finally, one has in the Operational Model 2 a truly realistic situation of engaged forces with no control over the environmental system parameters and very little knowledge of the actual atmospheric conditions in a rapidly changing environment. In Table 4 we see an assessment of the level of knowledge and importance of the value of the input parameters for the model output. It must be kept in mind that this is for controlled laboratory conditions in which the investigator has many first-principle, well-documented models and measurement apparatus for making detailed experiments on the aerosol. One can see that knowing the particle size distribution and the index of refraction is of critical importance insofar as the production of accurate values of the output quantities is concerned. Although models do exist for the computation of the output quantities for irregularly-shaped, inhomogeneous particles, it is usually very difficult to determine these properties experimentally. Particle shape can be of considerable importance in some cases, as in the comparison of water droplets and ice crystals. In table 5 we see the parameters for the Research Model 2

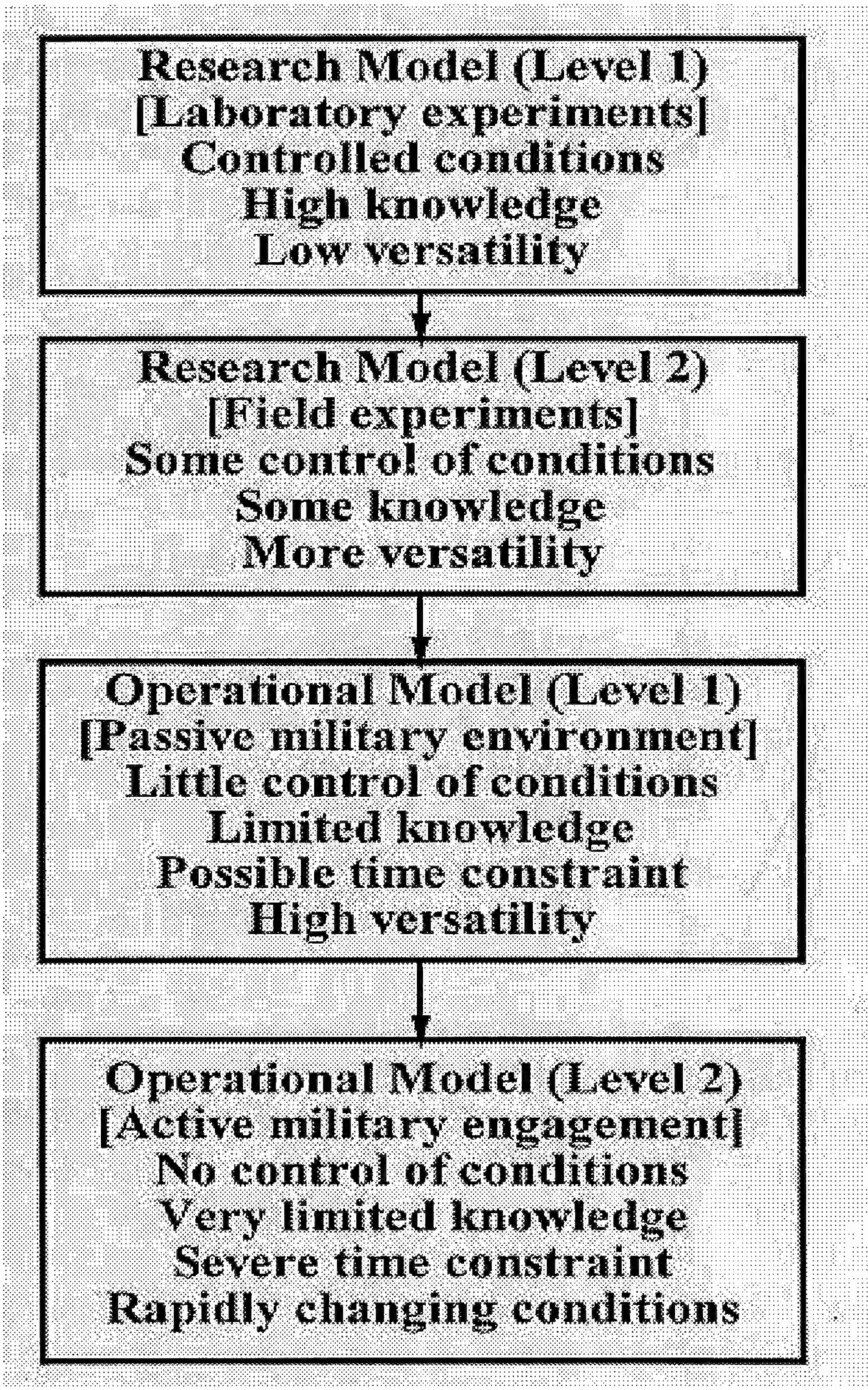

Fig. 10. Description of trade-off factors in the modeling of atmospheric obscurants

Research Model 1 (Output: cross sections, attenuation coeffs., phase functions)			
Input Parameters	Knowledge (theory)	Knowledge (data)	Importance
Size distribution	High	High	High
Index of refraction	High	Medium	High
Internal structure	Low	Low	Low
Shape	Medium	Medium	Medium

Table 4. Assessment of Research Model 1 Input Parameters

Research Model 2 (Output: transmittance, radiance, contrast)			
Input Parameters	Knowledge (theory)	Knowledge (data)	Importance
Attenuation coeff.	High	Medium	High
Scattering albedo	High	Medium	High
Phase function	High	Low to medium	High
Geometry & Time	High	High	Medium
Met. Data	High	Medium to High	High

Table 5. Assessment of Research Model 2 Input Parameters

Here we have a field experiment in which there is some control of the condition. The experimenter can at least determine the time of day, season, and location for the experiment. Also, time is usually not an important factor, so that one can set up equipment and, if necessary, perform the measurement several times. Thus, there is a high level of knowledge associated with the experimental design of the input parameters, although a lesser amount with the actual data because of the lack of sufficient knowledge in the weather parameters. The attenuation coefficients and the single-scattering albedo are quite important. For some situations it is not of critical importance to know the phase function. For an "benign" or passive military situation the parameters of importance are indicated in Table 6. Here we have the opposing force in view but no immediate

Operational Model 1 (Output: contrast, S/N, MDT, MRT, Lock-on-Range)			
Input Parameters	Knowledge (theory)	Knowledge (data)	Importance
Transmittance	Medium	Medium	High
Radiance	Medium	Low to medium	High
Geometry & Time	High	High	High
Background data	Medium	Low to medium	Medium
Met. Data	Medium to high	Medium	High

Table 6. Assessment of Operational Model 1 Input Parameters

engagement is anticipated so there is no time constraint. We have limited knowledge of the

background but we can obtain sufficient data on the meteorological conditions. It is important to have information on the LOS transmittance and the radiance but knowledge of such information may be somewhat limited because of denied access to the entire area. The output parameters that are of importance are the contrast and signal-to-noise ratio, and for infrared systems, the ranges associated with the minimum detectable and minimum resolvable temperatures. Finally, for a full military engagement the conditions are indicated in Table 7. Here, almost all input quantities are important but knowledge of them can be quite limited. Even the system-level models may not be appropriate for

Operational Model 2 (Output: contrast, S/N, MDT, MRT, Lock-on-Range)			
Input Parameters	Knowledge (theory)	Knowledge (data)	Importance
Transmittance	Low to Medium	Low to Medium	High
Radiance	Low to Medium	Low to medium	High
Geometry & Time	High	Medium to High	High
Background data	Low to Medium	Low to medium	Medium
Met. Data	Low to Medium	Low	High

Table 7. Assessment of Operational Model 2 Input Parameters

the situation. The third column indicates that knowledge of the input parameters may be to low for a successful mission. Factors to be considered in the Operational Model 2 are possibly severe time constraints as well as the rapid change in the values of the input parameters as military action takes place.

6.0 Problems (Models and Data)

6.1 Models

The basic models for the calculation of the microphysical data for the obscurants are generally quite good. This is also true for the transmission and radiative-transfer models that are used for the calculation of the radiance through a medium. What is lacking at the next higher level model (in a realistic environment) is a good description of the properties of the medium with respect to time and space as well as the appropriate mathematical description of radiation in this changing environment. What must be realized, however, is that even if a sufficiently advanced, detailed, deterministic, operational model were to be developed, the results would not be exact because of the uncertainties inherent in the limited data on which the models depend. Thus, it might be more reasonable to develop a stochastic model that predicts probabilities for the critical quantities in the operational mode based upon the partially measured probability distribution functions that characterize the statistics of a particular quantity.

6.2 Data

A fundamental question must be asked. How much do we know about the nature of atmospheric obscurants for any region of the globe for any period of time? Table 8 indicates the obscurants with an assessment of the degree of uncertainty in the critical i,arameters associated with those obscurants.

Obscurant	Operational Model Status	Data
Haze	Lack info. on vertical profile, particle size, and composition. Assume constant horizontal structure	Met. data may give visibility. No info. on particle size or composition. No info. on vertical profile
Fog	Reasonable models for particle size and composition but lack optical depth profile. Spatial inhomogeneity and time dependence are problems. Fog status depends on met. data	Met. data may give fog formation probability and fog type. No info. on optical depth or on vertical and horizontal structure. Time sensitive
Cloud	Reasonable for particle size and composition; optical depth, particle shape, and cloud structure are lacking	Coverage info. only. Some info. on cloud type and structure but no optical depth estimates
Dust	Particle size, shape, and composition quite dependent on environment and production mechanism	Very limited on composition, particle size, optical depth, concentration or production sources
Smoke	Lack info. on particle size, shape, and composition. Smoke cloud structure and optical depth not modeled. Time evolution not well modeled	Depends on source. Little info. on particle size or composition. General info. only on cloud structure. Quite time dependent
Rain	Good attenuation model but spatial and temporal effects not well understood	Met. data give some info. on intensity and visibility but lacking on horizontal spatial extent
Snow	Good attenuation models but depend on particle type, wind, and temperature	Met. data give some info. on intensity and visibility but particle type cannot be measured. Depends on wind
Other Precip.	Hail and sleet models need work. Spatial and temporal effects not well modeled	Met. data may give very limited info. on hail, sleet. Depend on temperature and wind

Table 8. Assessment of the status of operational models and data for the determination of obscurant properties on a global basis.

In almost all cases the basic models that are used for the determination of the microphysical quantities and the transfer of radiation either can be developed or are already in good condition. The major problem for the operational models lies in the mathematical description of the spatial and temporal variability of the concentration of the obscurants. There is an inadequate representation of the realistic conditions to be used for the basic models. Usually, the situation is even worse for the collection of data.

This is always limited, of course, and the problem then becomes one of careful experimental design, even for an actual military engagement

7.0 Improvements

How can we improve the operational models? There are two aspects to the problem. First, as indicated in Table 9, one can develop more realistic intermediate models that take into account either the actual spatial and temporal variability of the obscurants or their probabilistic nature with the use of stochastic models. Second, one

Obscurant	Operational Model Improvements	Data Collection Improvements
Haze	Create models to account for variation in particle size, composition, and overall structure.	Use lidar, RPV's, and satellites to retrieve data on visibility, optical depth, and particle size
Fog	Account for the overall structure and time dependence for fogs of different type. Stochastic models may be necessary	Must rely on met. forecasts and satellite data to provide info. on fog type and structure. Future satellite sensors may give optical depth
Cloud	Allow for variable geometric structure and optical depth. Better radiation models are needed for scattering, reflection, and emission. Relate to met. parameters	Use met. forecasts with stochastic models and use satellite measurement of cloud structure and radiation to infer optical depth and cloud composition (water vs. ice crystals)
Dust	Model various production mechanisms with greater fidelity. Allow for variable spatial and temporal effects and relate to met. parameters	Create inventory on surface composition for all regions of interest. Met. forecasts provide info. on surface state (damp, dry, etc.) and wind. Satellites give current data
Smoke	Account for variable spatial extent and time variation. Relate to met. data (R. H., wind speed and direction).	Use lidar, RPV's, and satellites to give info. on optical depth, and variable spatial structure with time. Also, info. on scattering albedo
Rain	Allow for variable spatial extent. Relate expected intensity to met. forecasts	Use radar, aircraft, and satellites to give info. on intensity and spatial extent.
Snow	Allow for variable spatial extent and snow type in terms of met. data	Use radar, lidar, aircraft, and met. forecasts for info. on snow type and rate
Other Precip.	Develop hail, sleet and mist models with greater fidelity in terms of met. data	Use radar, lidar, aircraft, and met. data for info. on type, size distribution, and rate

Table 9. Assessment of improvements for operational models and data for the determination of obscurant properties on a global basis.

can improve on the data collection methods that are used to provide the data needed as input to the computational models.

8.0 Conclusions

It must be emphasized that in almost all cases for obscurant models we already understand the basic physics of the interaction processes. What is distinctly lacking is a clear understanding of the variable nature of these obscurant properties and how to relate the variable properties to the necessarily sparse data that are measured as input to the models. Therefore, there are two major steps that must be taken to improve the overall fidelity of something that one might refer to as the "complete" operational model.

1.0 Most of the current obscurant models are of the classic "textbook" type in that they use simple representations for the geometry and variability of the obscurants. Hence, they are of limited use for a realistic portrayal of the modern battlespace environment. This situation can be improved by developing more realistic geometries for the expected scenarios and better algorithms for the connection between the basic obscurant properties and the standard meteorological data. In addition, one should develop stochastic models at least for the purpose of examining the statistical nature of the obscurants and to provide estimates of uncertainties in the final system-level output quantities needed for decision making.

2.0 There definitely needs to be an improvement with the data collection process, in terms of the type of data, the amount, frequency, and fidelity. Fortunately, much of this work can be performed now, even with limited data sets. Data acquired by the NASA, NOAA, and DoD satellites over many years can be assembled from existing catalogs. Data exist on soil type and conditions over extended regions of the globe, which will provide information on dust generation. Meteorological and climatological data can be analyzed with regard to conditions for the formation of haze, fog, and clouds for various areas of interest. With respect to future measurements, NASA has the Earth Observing System (BOS) which will provide useful information on models and algorithms for the satellite measurement of crucial optical properties of aerosols and hydrometeors. More work is being done with lidar for the measurement of these optical quantities and RPV's can certainly be used for surveillance situations.

With these improvements in operational models and data collection methods, military commanders of the future should have more reliable and realistic techniques for the analysis of natural and anthropogenic obscurants in the modern battlespace arena.

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SENSOR VISION IN DEGRADED ENVIRONMENTS: MODEL LINKAGE PROCESS

James F. Nealon
Survivability/Lethality Analysis Directorate
U.S. Army Research Laboratory
Aberdeen Proving Ground, MD 21010-5423
Phone: 410-671-3711
Fax: 410-671-3471
E-Mail: j fnealon@arl.mil

TRACK Simulation, Obscurants, and Sensor Technology Group, Obscurants Sub-Track

ABSTRACT

Modern combat vehicles rely upon advanced sensors, such as Forward Looking Infrared (FLTR) sensors, image intensifiers, and low4ight television, to detect, acquire, and defeat threat vehicles. These sensors increase in importance under degraded visibility conditions. Factors such as detection range; time required to detect; and probability of detection are crucial in determining who fires first in an engagement. The first shot can also be the only shot; therefore, firing on the correct target first can also increase vehicle survivability. This paper addresses an attempt to model this comparison, using a meeting engagement as the test case. On-board obscurant assets were the only materials played. Vehicle self-defense obscurants were modeled in the Combined Obscuration Model for Battlefield-Induced Contaminants (COMBIC). COMBIC outputs were linked to input files for the ACQUIRE target acquisition model. ACQUIRE was used to model acquisition probabilities; time requirements; and range of acquisition for specified vehicles, using a range of several possible sensors. These factors were compared, for hunter-target pairs, using both friendly and threat vehicles as the hunter. Results and insights gained were summarized, and additional applications were described.

1. INTRODUCTION

There are many ways to model, view, or simulate obscurant clouds. There are also several ways to simulate vision through the obscurant cloud. There was no method to use both sets of information to perform one-on-one or one-on-many analyses. This paper was written to demonstrate the methodology used in linking obscurant effects, from aerosol models, to anticipated results from sensor vision models. The linkage methodology was developed by the U.S. Army Research

Laboratory (ARE), to provide a standard methodology and procedure for linking obscurant conditions to the effects induced on the sensors. The methodology and results described below were used for several ground and munition system programs analyzed by personnel at the Survivability/Lethality Analysis Directorate (SLAD).

2. BACKGROUND

Several ground system programs have needs for preliminary system analyses by SLAD. The analyses are needed to measure either obscurant effects on their sensor package, or survivability enhancements from using proactive or reactive obscurants. Other ground systems or munitions require analysis of system effects under experimental conditions, and extensions of this analysis into other climatic or weather regions. Experiments were limited by the project flinds, available to either SLAD or the customer, because field experiments are vey expensive. Threat-based effects, or effects under different climates and theaters, were not addressed well in some analysis efforts because there was no common method or procedure to use in an analysis. There was no apparent system to link information from atmospheric or aerosol models to sensor or vision models. The models might also omit or understate aerosol effects, such as scatter or radiance, because their focus appears to be transmission effects.

SLAD uses a standard taxonomy structure to address survivability and lethality issues (Figure 1). The taxonomy is a useful tool, but requires some care in use for analyzing sensor effects. The methodology described below is a way to implement the taxonomy, with respect to obscurant and aerosol effects. This analysis methodology was built to account for modeled weather and aerosol

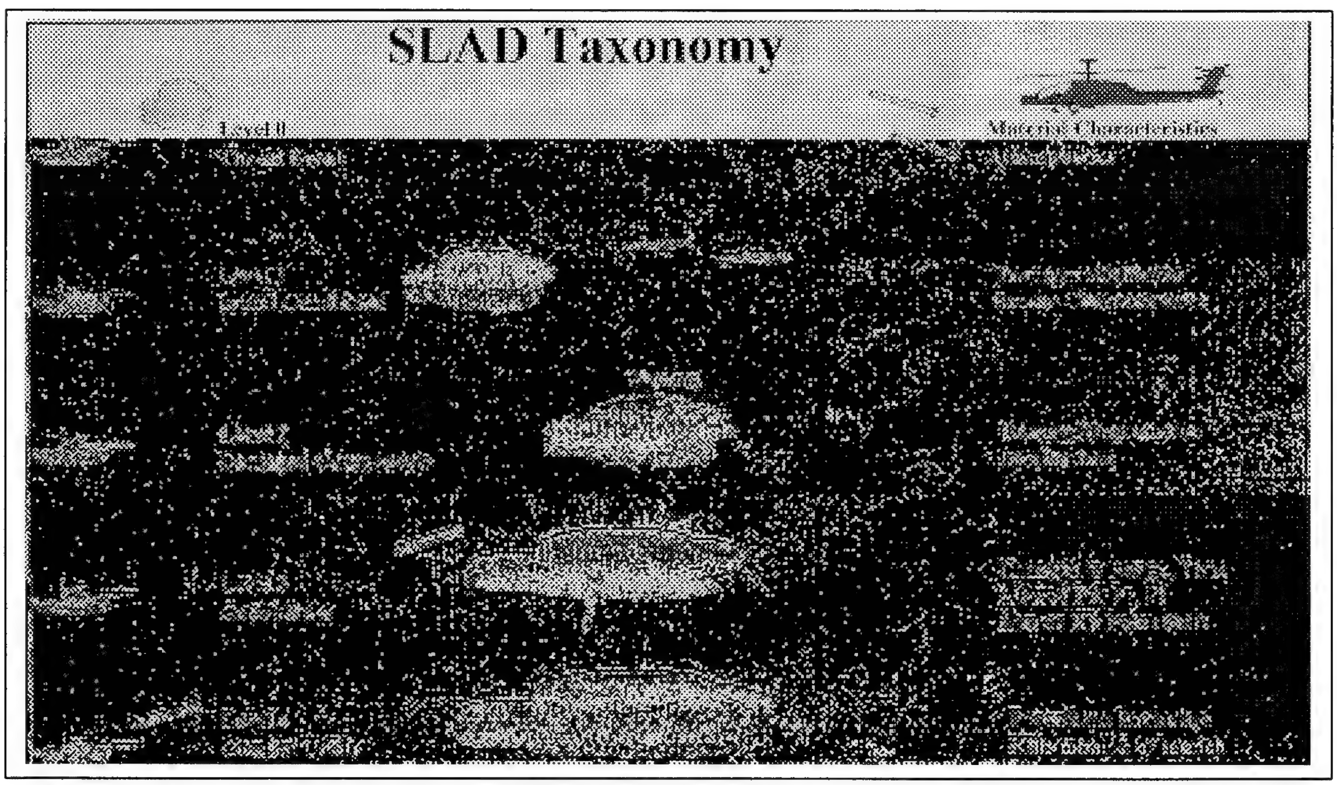


Figure 1. Overview of SLAD Taxonomy (Obscurants Emphasis)

effects in different climates; use aerosol model results as inputs for the vision models; and analyze the results in terms of battlefield capabilities.

3. CONSTRAINTS ON ANALYSIS AND MODELING

The sensor and model analyses were restricted to relatively small spaces, to reduce analysis time and to focus on areas of most interest first. Some of the treatments for atmospheric conditions and energy interaction have limits on the approximations used. The models all have boundary conditions, and rely upon certain assumptions. It's possible to overstep these boundaries and assumptions if the models are not linked properly. These constraints are described in succeeeding paragraphs.

3.1 SENSORS

Direct-fire acquisition systems (ground to ground or air to ground) were used for the model process. The sensors used in this study were first and second generation forward looking infrared (FLIRs), for direct fire applications (cannon, missile). Generic sensor descriptions were modeled from ACQUIRE' standard inputs. Sensor analysis required the operator of a hunter vehicle to be able to detect, identify, and then engage a possible target. The sensors used were based on open literature citations for NATO and former Soviet Union AFVs. Given the state of flux in some regions of the world, there may be potential for sensor upgrades as part of "third party" or customized platform improvements.

The sensor analysis used limits on search time in the field of regard and on search time within a given field of view. These times were kept short, to represent the times that could occur in a meeting engagement between two (small) forces. The analysis focused on the search and acquisition situations likely to occur either early in, or at the end of, a meeting engagement. The vehicles here were constrained to find opposing targets in the early stages of engagement, for direct fire combat. Similar constraints also apply for forces disengaging from combat for repair or resupply

3.2 CLIMATES AND THEATERS

Climate conditions possible in southwest Asia, northeast Asia, and central Europe were modeled, to provide finite boundaries on the problem space. The climate areas were selected because they represent high visibility areas, commonly seen on broadcast and cable news. These areas show apparent high levels of ethnic or international tension, exacerbated by resource shortages or inefficient economies. They also represent a reasonable cross-sections of arms sales for NATO and former Soviet systems. Daytime climate conditions are described in Table 1 for Middle East desert conditions, obtained from CLIMAT (three most likely conditions). The values are representative of possible weather conditions, natural aerosols, and wind/stability combinations. The climate conditions are further bounded by limiting the ground range of interest to 10km, and air altitudes to about 1km. This simplified the atmospheric modeling, while avoiding any overemphasis on certain extinction effects. This bounds the line of sight value for open, gently rolling terrain.

TABLE 1. DAY CONDITIONS, MIDDLE EAST DESERT (SPRING)

Type	Description	Temp, deg C	RH, %	Visibility, km	Windspeed, m/s	Pasquill Category 6
Dust with visibility> 3 km		28.2	25.9	8.5	6.7	D/C
15	Noweatherandabsolute humidity < 10 gm/m^3	21.1	34.6	17.7	3.8	BID
16	No weather and absolute humidity> 10 gm/rn^3	25.0	54.0	15.2	3.8	CID

Conditions 15 and 16 represent the majority of conditions to be expected during daylight hours (1000 - 1400). This includes warm temperatures, moderate winds, and a neutral to slightly unstable air condition. Obscurants used under these conditions will have moderate duration.

3.3 OBSCURANTS

The obscurants used in this study were taken from unclassified sources and from unclassified NATO documentation/descriptions. The phosphorous and bispectral grenades studied were L8A3 and M76 screening grenades, used in conjunction with M239 or M243 series smoke grenade launchers. The UK L8A3 was adopted (with its launchers) by the U.S. Army in 1976. The M76 IR screening grenade, which is used with the same launchers, was type classified in 1986. Both grenades have been used in field experiments and have been used in NATO exercises and tests. The L8A3 smoke grenade produced scatter and attenuation in the visible and near IR bands; some far IR attenuation occurred, in combination with increased clutter. The M76 produced attenuation in all bands from visual through far IR.

Three mechanisms are postulated for obscurant effects: absorption, scatter, and radiance (emission). Attenuation is a combination of absorption and scattering; this is commonly considered the principal effect of obscurants. Absorption decreases radiation propagation, in a given band, through the material. The energy absorbed can be re-radiated at different frequencies, or can be re-radiated out of the path to the receiver, resulting on signal loss. Scatter can reflect laser or radio frequency (RE) energy, depending on the obscurant, creating false signals or cluttered returns. Radiation can be scattered into or out of the signal path. Radiance involves the release of large amounts of energy from pyrophoric materials or from warm obscurant clouds. This produces additional hot spots or warm areas in a scene, changing the background distribution and altering the signal to noise ratio. The effect is most pronounced in the mid and far IR.

The taxonomy describes a strategy for analyzing effects, from initial conditions present through the degraded capabilities for the system. Obscurant conditions can include reduced transmission, radiation scatter, and emission (radiance). The resulting degraded conditions are:

a. <u>Contrast reduction</u>. Attenuation, which is a combination of absorption and scatter, can alter a target's apparent contrast with the background. This can make it harder to distinguish a target from its background.

b. <u>Signal reduction</u>. Radiation scatter through an obscurant, or through a hazy atmosphere ("clear air"), can alter the apparent structure information for the target. Out-of-path scatter can blur edges or feature, which makes it harder to detect or classify a target.

c. <u>Clutter</u>. Emissive materials can create relatively warm obscurant clouds or hot elements in a scene. This additional clutter can alter a scene's structure, and can hide or alter target structure. They can also introduce false targets or false features into the scene.

Obscurants were placed with a tail wind, to move the obscurant from the target vehicle toward the observer (hunter) (Figure 2). This also can be modeled for head, cross, or quartering winds. The range description also shows relative range scale, and the size of range cells used for estimating obscurant concentrations and transmission.

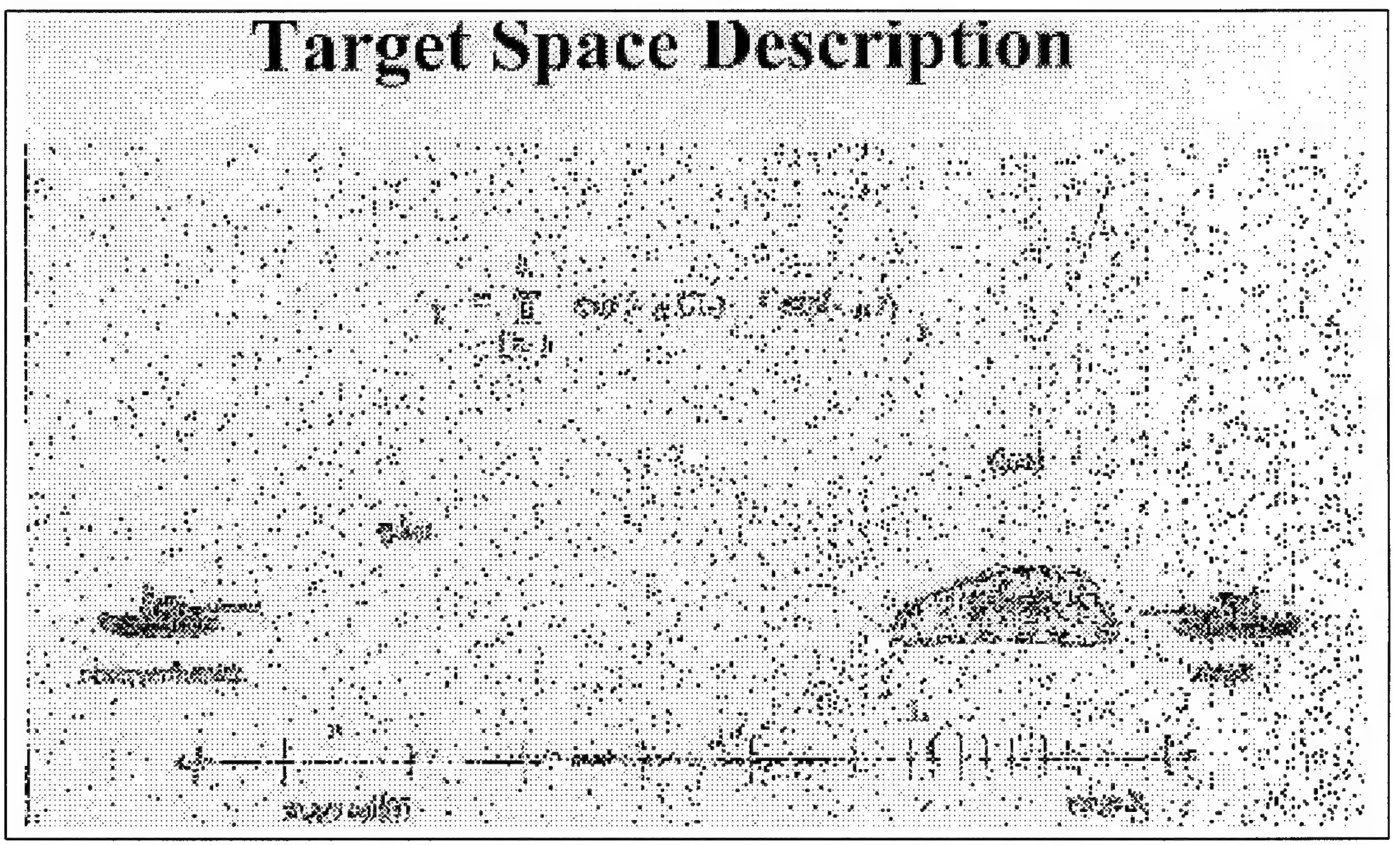


Figure 2. Target Space Description for Analysis

4. METHODOLOGY

The methods used below were intended to describe target acquisition parameters, given known or modeled inputs on the sensor type, atmosphere, and other conditions. This methodology also looked for areas where the models did not interact well, or where the input information could not be easily translated between models.

4.1 ATMOSPHERIC AND AEROSOL CONDITIONS

The study methodology was based on the need to estimate transmission through range cells along a path from the target to the receiver. Basic atmospheric transmission was modeled in XSCALE[2], using climatic conditions (2-3 most common cases) from CLIMA~f. COMBI~ was used to model obscurant transmission within the area of interest, in the small range cells. The composite relation of range and transmission was used as an atmospheric input to ACQUIRE.

4.2 ACQUISITION MODELING

ACQUIRE was used to model target acquisition by IR imagers (first or second generation FLIR). Unclassified target and sensor descriptions were used for this analysis. ACQUIRE outputs were used to get estimates for probability of detection at different ranges, and also to obtain estimates for time required to find a target at range. The target was an Mi-sized target, with a given temperature of 2 degrees C above background. Low and moderate clutter conditions were used. Target range was fixed at 2km for the trial cases presented here, to bound the problem space.

4.3 MODEL LINKAGE

COMBIC and ACQUIRE were linked by means of an Excel(TM)[5] spreadsheet. COMB IC was used to develop range cell profiles of transmission in an obscurant cloud, and also to develop cross-axis profiles of the cloud width. The along-axis profiles were combined, in the spreadsheet, with atmospheric extinction determined from CLIMAT and XSCALE. This provided the range -transmission pairs needed to explicitly define an atmosphere condition for ACQUIRE. Clutter could be simulated only by altering the number of cycles needed for response (n50 for detection, recognition, etc.) under the Johnson criteria. Target contrast changes were not easy to describe for ACQUIRE. The ACQUIRE outputs for these conditions were then imported back into the spreadsheet. The data were parsed and plotted to provide graphic representations of probability of detection (Pd) and range; Pd and time, and range and time for a given Pd condition. The spreadsheet related two different input-output requirements without needing an elaborate interface or re-coding effort. The spreadsheet also made it possible to change assumptions or graphical techniques rapidly. The graphical products could also be copied or linked easily to other applications, such as presentation or word processing packages, for easier communication of results.

5. RESULTS

5.1 AEROSOL AND ATMOSPHERIC EFFECTS

CLIMAT was run first, to get predictions for climatic types possible in the areas of interest. The three highest probability conditions noted in CLIMAT were used in COMBIC, to model effects from natural aerosols in combination with the man-made obscurants. One set of southwest Asia (SWA) conditions is presented as an example case. COMBIC was used to model spring day conditions for climate condition 16 (wind 8.5 kts (3.8 mls), Pasquill category C, day, temp 25 deg C, RH 54%). Attenuation profiles are shown below for 6 M76 grenades; mix of M76 and L8A3 grenades; and L8A3 smoke grenades (6) with vehicular dust effects. The wind direction was a tail wind behind the target vehicle, blowing toward the observing vehicle. Figures 3-5 shows the transmission time history along the center axis of the modeled line of sight. Figure 6 describes the approximate cloud effect across the wind axis.

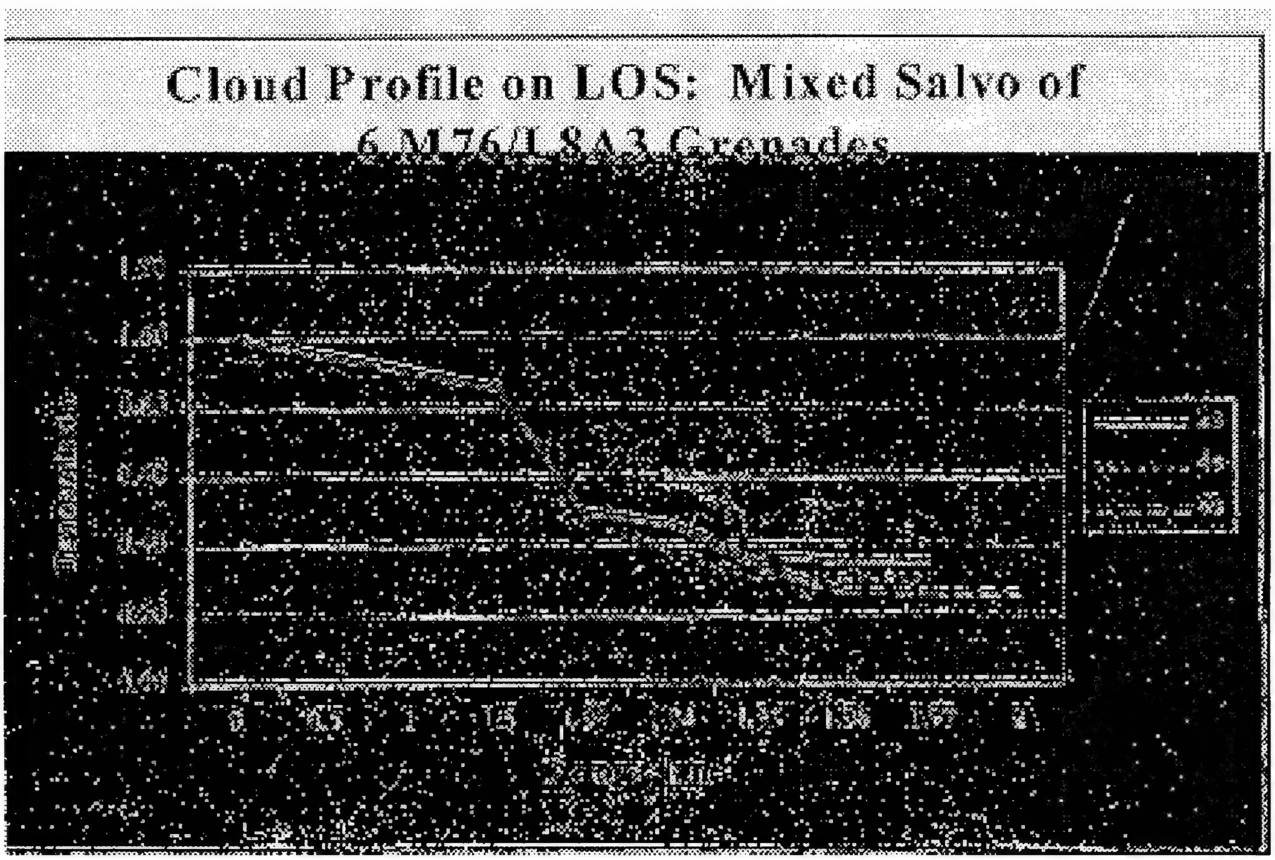
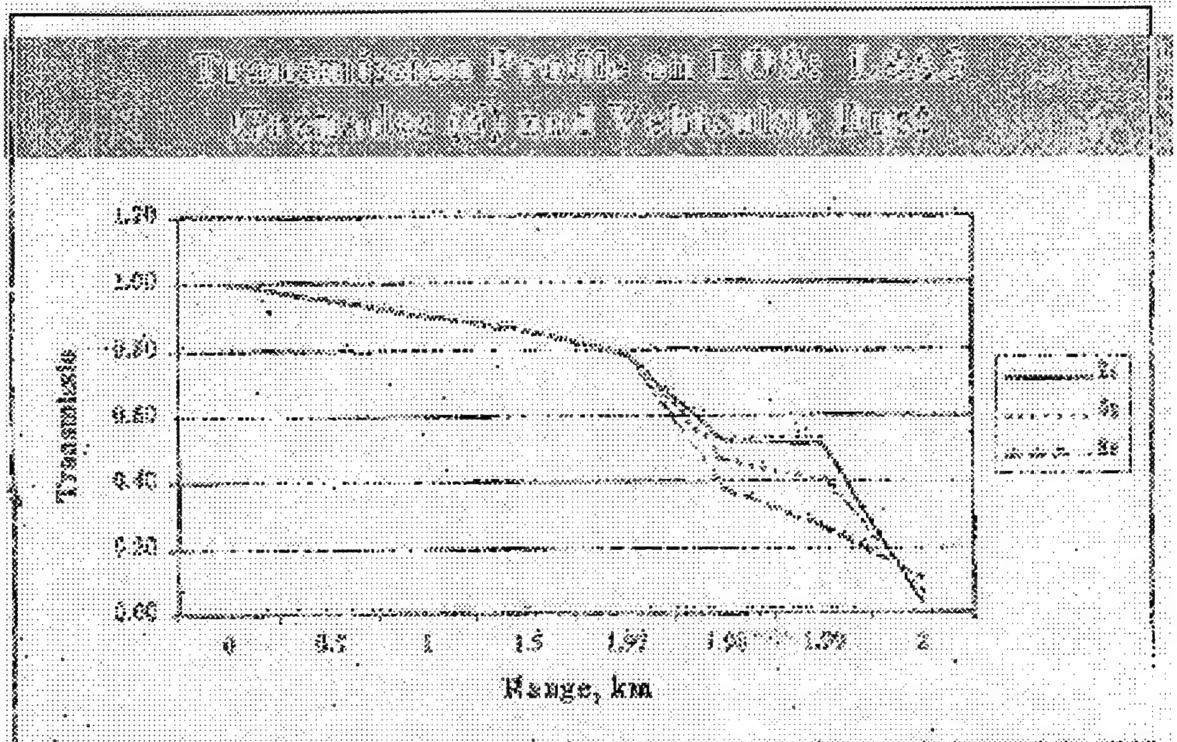
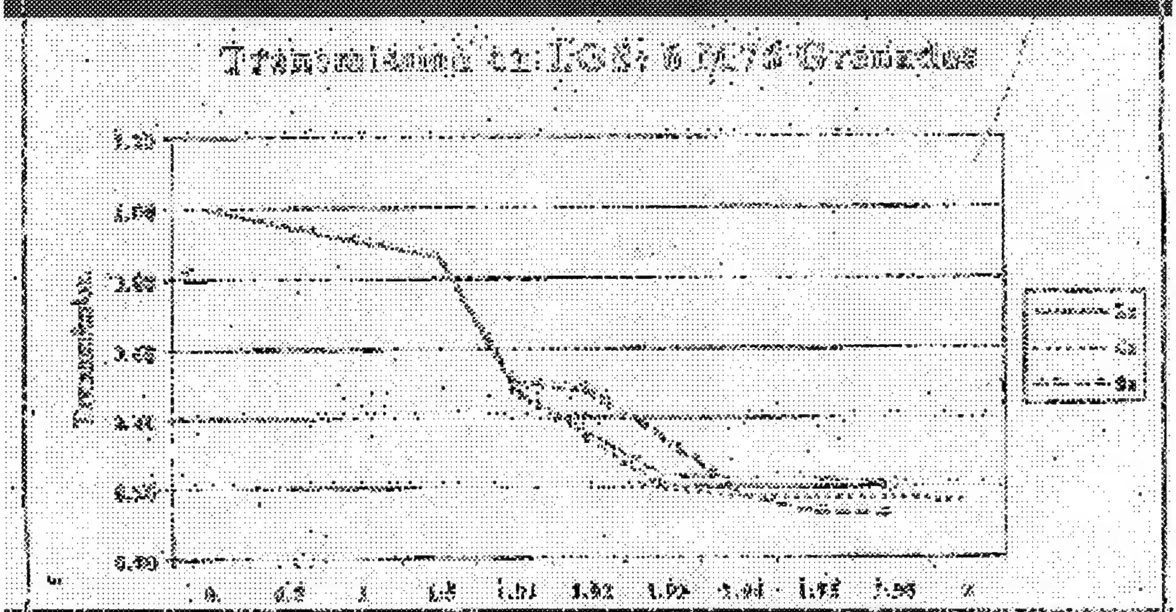


Figure 3. Transmission along LOS for mixed salvo of six grenades



Transmission
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
0.5
1
1.5
2
Range, km



1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.5
1
1.5
2

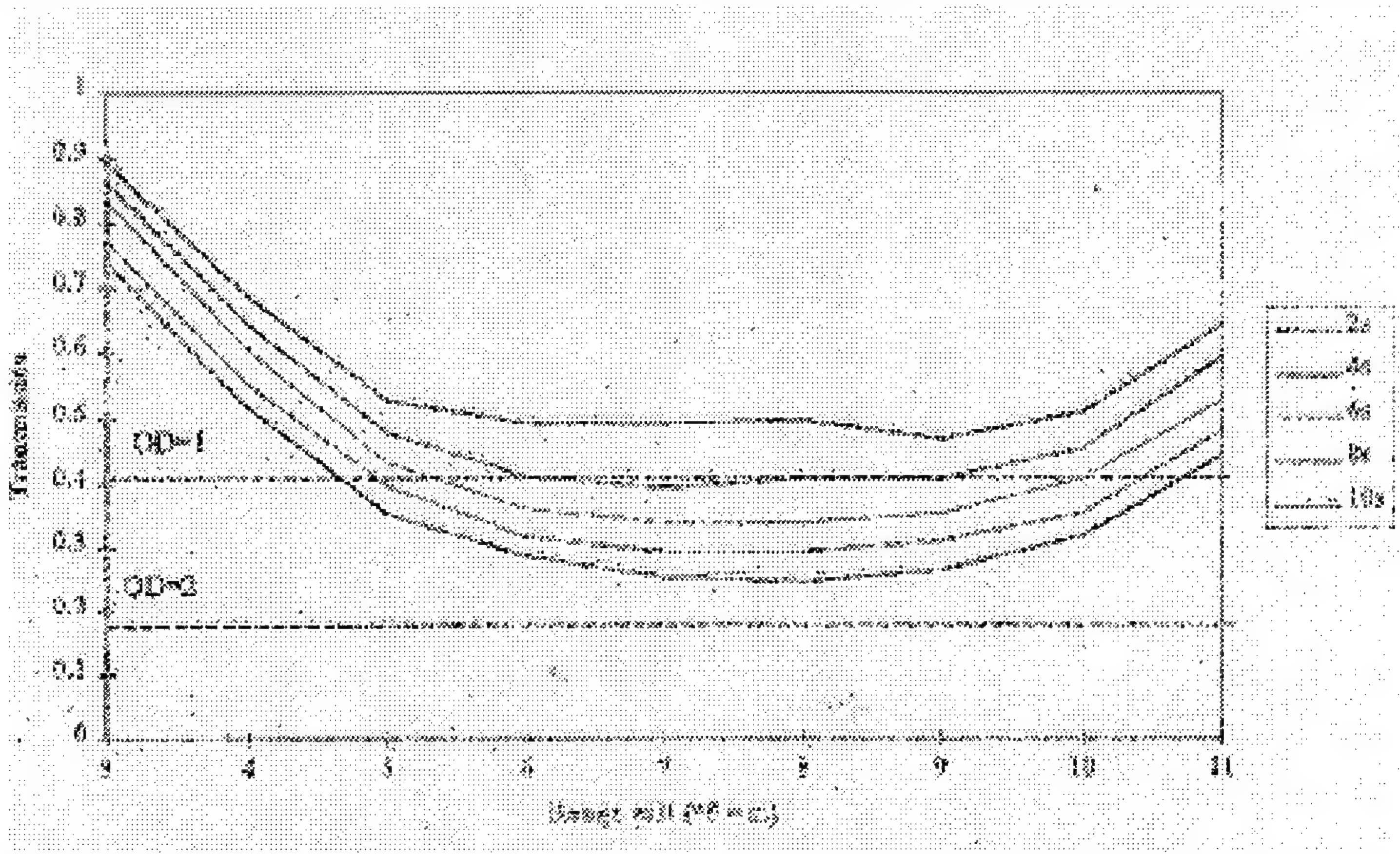


Figure 6. Cross-win axis profile, Salvo of 6 M76 grenades (5 meter cells)

The optical density of the cloud changes with time after dissemination, wind speed, atmospheric stability, and other factors. Optical densities (OD) of 1 or 2 (37% or 16% transmission) can occur relatively fast, and can remain on the line of sight for periods of time. Many advanced sensors have performance requirements for obscurants expressed in terms of OD or transmission.

5.2 ACQUISITION EFFECTS FROM OBSCURANTS

Obscurant profiles were shown in Figures 1-3, with early cloud development described. These clouds continued to develop for about 30s, then began to disperse. Direct fire weapon effects involve obscurant effects on FLIRs or other sensors. Nominal missile or projectile flight times are shown in Table 2).

TABLE 2. ESTIMATED TIME OF FLIGHT FOR DIRECT FIRE ENGAGEMENTS

Munition Class	Nominal Velocity, mls	Nominal Time of Flight to Target at Range, 5			
		1km	2km	3km	4km
ATGM	200	5	12	25	30
Cannon (KB or CE)	2000	0.5	1	2	3

Table 2 shows that unguided attacks (cannon fire) arrive very quickly after engagement and firing; obscurants may not have much effect afier engagement begins, at short range. However, the guided munitions (ATGM) can require sufficient time of flight to encounter a cloud of OD 1 to 2 (transmission below 40%) for an area 20-40m across. In-flight and terminal guidance can be affected by interfering with the operator's scene picture (obtained from optics or FLIR) or by disrupting data links. The operator can lose lock on the target. The degradation mechanisms are contrast reduction and reduced signal strength. U.S. doctrine is to use the prevailing winds, and cloud movement, to hide a vehicle behind the self-defense obscurant[6]. The vehicle can then enter defilade behind terrain features while either evading attack or returning fire.

The cases above show obscurant effects for targets acquired by advanced sensors. This begs the question that detection has already occurred. Detection effect from obscurants were modeled with ACQUIRE, and are described below (Figures 7-8). The cases shown were the M76 6 grenade salvo, and a salvo of6 L8A3 grenades with vehicular dust. The mixed salvo (L8A3 and M76) and L8A3 salvo with dust were modeled with an increased clutter level, due to small fires and radiance from the RP pellets. An Ml size target, with a background temperature difference of2 degrees C, was used for a target vehicle. The acquisition sensor was an "average" first generation FLIR.

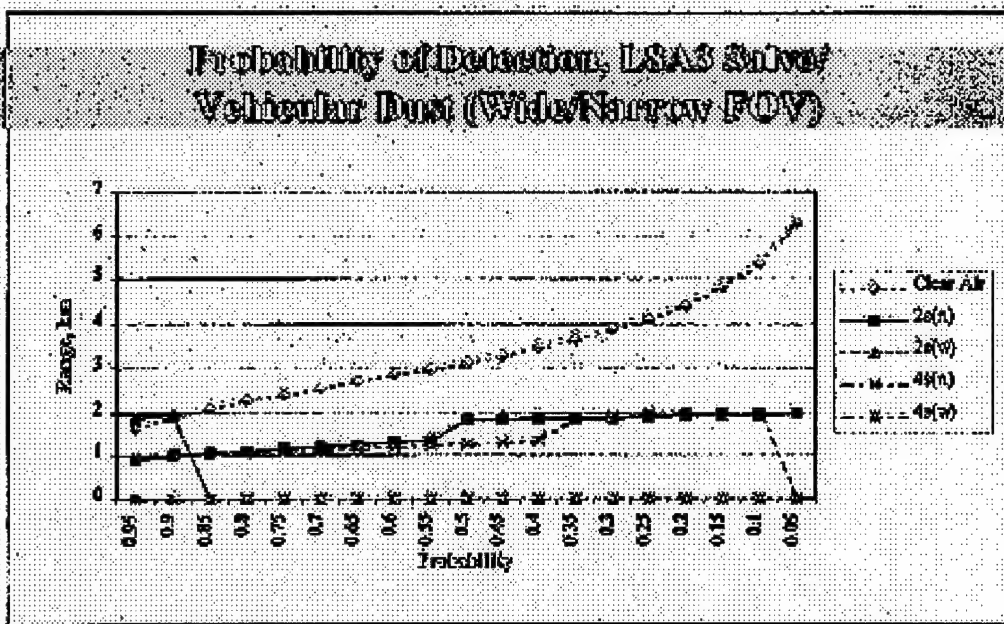


Figure 7. Probability of detection (wide/narrow FOV), LSA3 salvo with dust

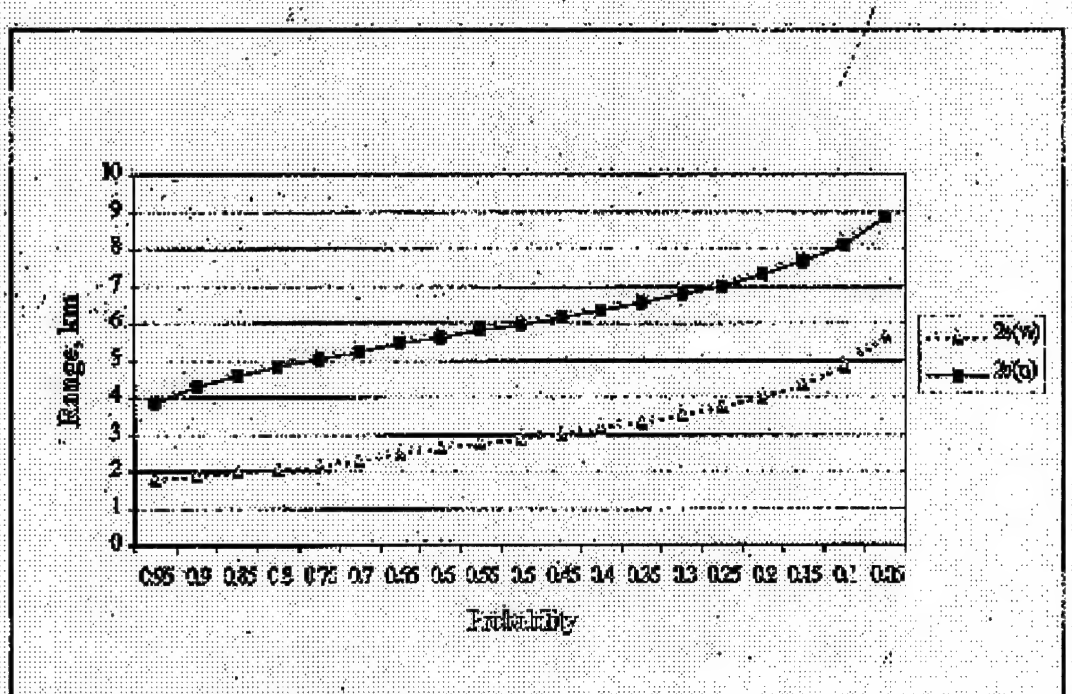


Figure 8. Probability of detection, M76 salvo (5)

6.ANALYSIS OF ACQUISITION EFFECTS

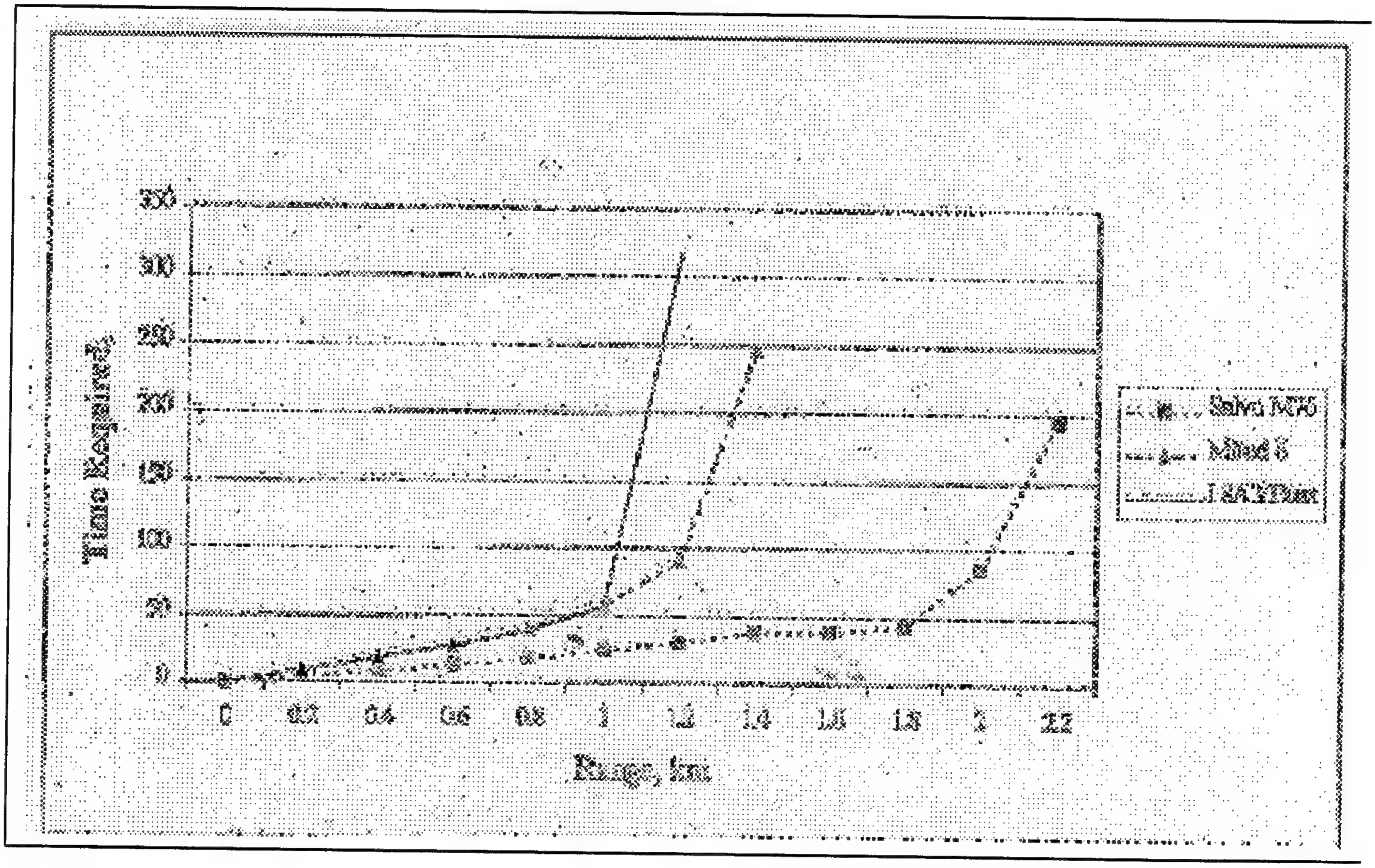
Target acquisition was analyzed. This meant examining acquisition probabilities at given ranges, as well as times required to detect and acquire targets.

6.1 TARGET DETECTION

The probability functions (Figures 7-8) show the probability of detection (wide or narrow field of view (FOV)), for times tending to infinity (ideal case). A system attempting to acquire the target must first detect it. Detection may probably be in the wide FOV, but may be in the narrow FOV if the observe had time to scan the operating area first. The target would be hard to find if a 6 grenade M76 salvo is used (Pd about 70% at 2 km, in 2 5, Pd about 45% at 8s). The L8A3 grenade salvo, with vehicular dust accounted for, becomes very hard to detect at 2km (Pd (wide) about 15%, Pd (narrow) about 80%) for a first generation system; more important is the effect of the combined dust plume and phosphorous cloud. The target becomes very difficult to detect at ranges beyond 2 km, due to the dense cloud produced. The target would be able to hide or maneuver behind this very dense cloud. This cloud produces even stronger effects at times of 4s and later.

6.2 TIME REQUIREMENTS

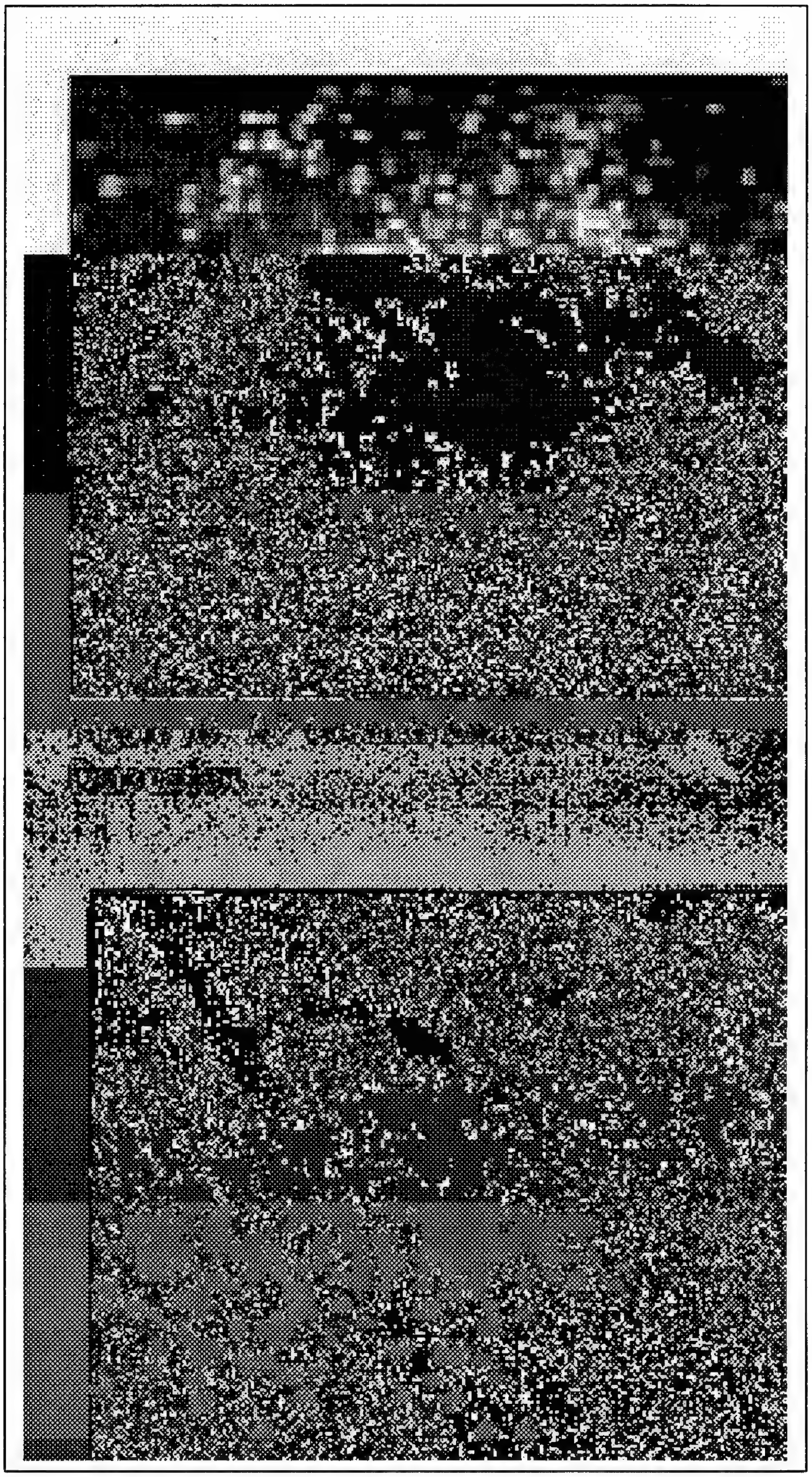
Time required to detect a target also becomes important. The probabilities in Figures were developed using a 30s search time over a 60 degree field of regard. The time requirements for a high probability of detection, for the above grenade uses, is shown in Figure 9 below. These times were developed at 2s afier grenade detonation. Probability of detection was chosen as 70% to give the hunter a better than even guess at the target, while keeping the time required to detect below the infinite amount needed for a perfect detection. Its target can be detected, but it can take 80 seconds to achieve a good detection in the presence of obscurants (M76). The target may not be detectable at the studied range when a mixed salvo, or an L8A3 salvo with dust is considered. The contrast level is reduced and background clutter is increased.



6.3 OBSCURANT IMPACTS

The ACQUIRE detection time, for clear air conditions (before obscurant use), show approximately 33 seconds for detection by either hunter or target at 2 km range. If the target vehicle is found first, then obscurant effects are as described above (limited reaction time). If the observe (hunter) vehicle is found first, the target can employ obscurants, make evasive maneuvers, and attempt to fire or disengage. If the target vehicle can survive for about 6-8 seconds, the probability of detection drops significantly and the required search time grows large. This is a combined effect of increased range and obscurant cloud growth. The probability of engagement drops because the target is much harder to find. The observer vehicle must then decide whether to attempt reacquisition or disengage and find a less wary target.

The depictions for phosphorous grenades are of interest, for the possible clutter impacts. The changes in discrimination values (n50) are based on changes in the scene clutter and on some possible false targets introduced into the scene, when viewing the area from a 2km distance. The changes have moderate duration (30-60s), depending on local climate and meteorology conditions. This can be sufficient time to alter the search and acquisition characteristics. Other radiant materials, such as grenades from other nations or artillery/mortar fire with WP ammunition, can have similar effects. Figures 10 and 11 show two time histories of an RP grenade image. The burning RP pellets



are distributed across a 1 Om diameter area, based on the distance and resolution of the Agema imager. These hot spots and warm cloud elements, when viewed from a distance, cold add clutter to the scene. They may also be misinterpreted as having target-like features, especially if viewed with a low-resolution sensor. Images and data like those below were used to justify the increased clutter level for the phosphorous grenade modeling

6.4 FEASIBILITY OF MODEL LINKAGE

COMBIC produced large amounts of data for the obscurant cloud transport and fate. The output file could be imported into Excel(TM) with little trouble, as a delimited file. This file needed to have header information pruned, and the output data sorted, to be of further use. Atmospheric transmission coefficients could be extracted from XSCALE and CLIMAT with little difficulty, and used as "constants" for a given environmental run. It was possible to take time-based slices of the cloud, determine where the cloud boundaries appeared, and build a small table for range and transmission. These columns were exported as delimited data to become part of the ACQUIRE inputs. Multiple ACQUIRE runs were conducted using these exported files, with the correct run separators supplied. This reduced the ACQUIRE run time by doing batch operations. The data slices were cut off at about 3 Os after detonation of grenades, as the clouds would begin to disperse then. The operations could be conducted with relatively simple spreadsheet macros, after initial manual efforts to determine that the correct data were used and processed.

ACQUIRE run analysis was simpler, as this required parsing of portions of the ACQUIRE output files. This could be accomplished by the appropriate macros, to speed up processing. The most time-consuming portion of the ACQUIRE analysis was determining what variables to graph, and to show what information as being most interesting.

The n50 vaues used in this analysis were based on analysis by other agencies (AMSAA, CECOM Night Vision Directorate) for similar sensors. The analysis was done for benign conditions, principally, because few obscurant data points were available for the ranges and scene conditions. The n50 value appears related to the false target density and to an estimate for scene clutter levels (low through high). Attenuating obscurants can reduce clutter in the local area by suppressing clutter elements in the background, so the n50 values were not raised much. Emissive materials, such as phosphorous, can introduce more clutter and possible false targets. The n50 values were raised moderately, to account for these combined effects. Additional obscurant data, for the backgrounds and clutter levels studied, would allow for developing a non-benign set of n50 relations; this would ease the task of linking model results and obtaining relevant predictions.

7. CONCLUSIONS

7.1 Fielded or type classified obscurants can affect advanced sensors used to detect and acquire targets. This can have impact on system performance modeling. Obscurant effects can be modeled in COMBIC and linked with programs such as ACQUIRE. Follow-on modeling, with other obscurants, can be conducted to estimate effects for other common materials.

7.2 ACQUIRE can handle obscurants as an explicit Beer's Law entry, or as an implicit portion of an atmosphere profile. This accounts for direct transmission reduction, but does not necessarily account for energy scatter and transfer from the surroundings. The additional energy from out-ofpath scatter, sky and ground sources can induce contrast changes and can affect how a human detects a target. The ACQUIRE modeling team should discuss the implications of scene models, such as PILOT8 1, with SLAD to examine these additional effects.

7.3 Models such as COMBIC and ACQUIRE can be linked by intermediaries such as spreadsheet programs. The spreadsheets were very useful in visualizing the obscurant clouds and the related effects on target acquisition. SLAD should continue the efforts to automate the data extraction and transformation, and make this linkage process more efficient.

7.4 Clutter and false alarm density must be modeled (indirectly) as changes to the nSO characteristic values in the model. These effects are not played directly in the model. SLAD analysts are working on several approaches to portraying combined effects from obscurants, other aerosols, and false targets or induced clutter. This can provide better inputs for the target acquisition models.

ACKNOWLEDGMENTS

The author wishes to thank Ms. Jill Thompson and Dr. Young Yee, of ARLIS LAD, Atmospheric Effects Branch, and Dr. James Liu, ARLISLAD Ground Systems Branch, for their review and critique of the methodology proposed in this paper. Their insights were important in keeping this analysis technique focused on the results needed for modeling sensor acquisition effects. Messrs. William Pibil and John Mazz, of the U.S. Army Material Systems Analysis Activtiy, were extremely helpfiil in explaining the relationship among false target density, clutter, and characteristic values. They allowed the author to correlate the modeled effects with real-world observations.

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Sensor Vision in Degraded Environments: Model Linkage Process

James F. Nealon

Survivability/Lethality Analysis Directorate

U.S. Army Research Laboratory

APG, MD 21010

jfnealon@arl.mil

Outline

- Introduction
- Background
- Methodology
- Aerosol Modeling
- Model Linkage
- Acquisition Modeling
- Results
- Conclusions
- Insights for Future

Introduction

Army Research Laboratory

Survivability/Lethality Analysis Directorate

- Model obscurants: COMBIC, LASS, etc.
- Model sensors: FLIR, ACQUIRE, etc.
- Ability to work together?
- Constraints?

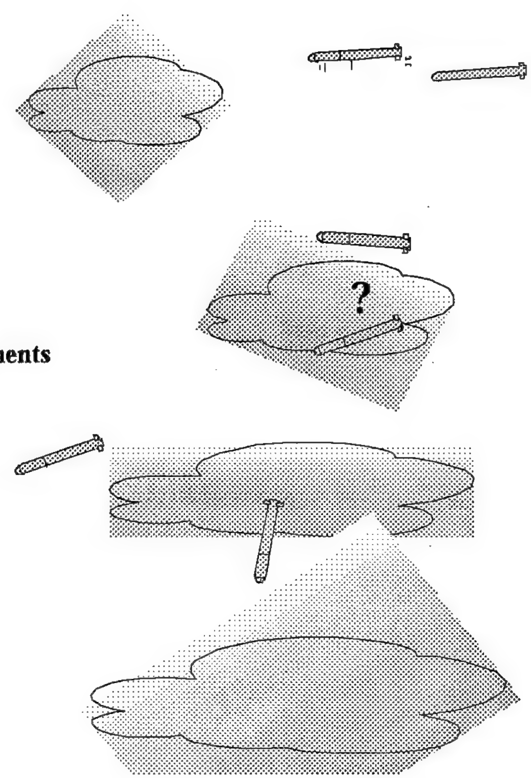
8/13/98

Background

- Model obscurant/aerosol effects for ground systems
  - Regions and seasons (materials)
  - Weather conditions, atmosphere, time of day
- Tie obscurant effects to warfighting capability
  - Fire control sensors: FLIR, laser, optics?
  - Defensive armament/ CM protection?
- Lack of links between models
  - UNIX or PC
  - I/O formats
  - obscurant and natural environment
- Ability to view inputs/results in graphical format

SLAD Taxonomy

Level 0 Threat Event	Material Characteristics Atmospherics
Level 1 Initial Conditions	Transport/Diffusion Sensor Characteristics
Level 2 Damaged Components	Damage/Degradation Mechanisim
Level 3 Capabilities	Changes in Range, Time Altered Pd, Pr, Pi Aim or Hit Point Shift
Level 4 Combat Utility	Force/Loss Exchange Kills/mission or launch



Methodology

- Model obscurants in COMBIC
  - selected materials: M76, L8A3, vehicular dust
- Convert transmission to ACQUIRE inputs in Excel(TM)
- Model effects in ACQUIRE for selected times

8/13/98

Aerosol Modeling

- Concentrate on attenuation
- COMBIC: obscurant modeling
  - range-resolved LOS from target to observer
  - fielded (common) materials: grenades (M76, L8A3), vehicular dust
  - conditions: SWA spring, early in day (T = 25 deg C, wind 3 m/s, Pasquill B/C)
- CLIMAT: Climatic conditions expected in region
  - visibility, temperature, Pasquill category, etc.
  - rough probabilities for weather events
- XSCALE: Natural environment condition
  - atmospheric extinction

Model Linkage

- Incorporate natural atmosphere extinction
  - calculate combined transmission for natural and man-made aerosols
  - Beer's Law format
- Build along target - receiver LOS
  - Larger range cells: atmosphere (0.5 km)
  - Smaller cells - obscurants (0.01 km)
  - Tail wind case chosen (target to observer)
- Convert to ACQUIRE input form, pair range and transmission
  - Calculate range from observer to target
  - Calculate transmission in applicable range cells

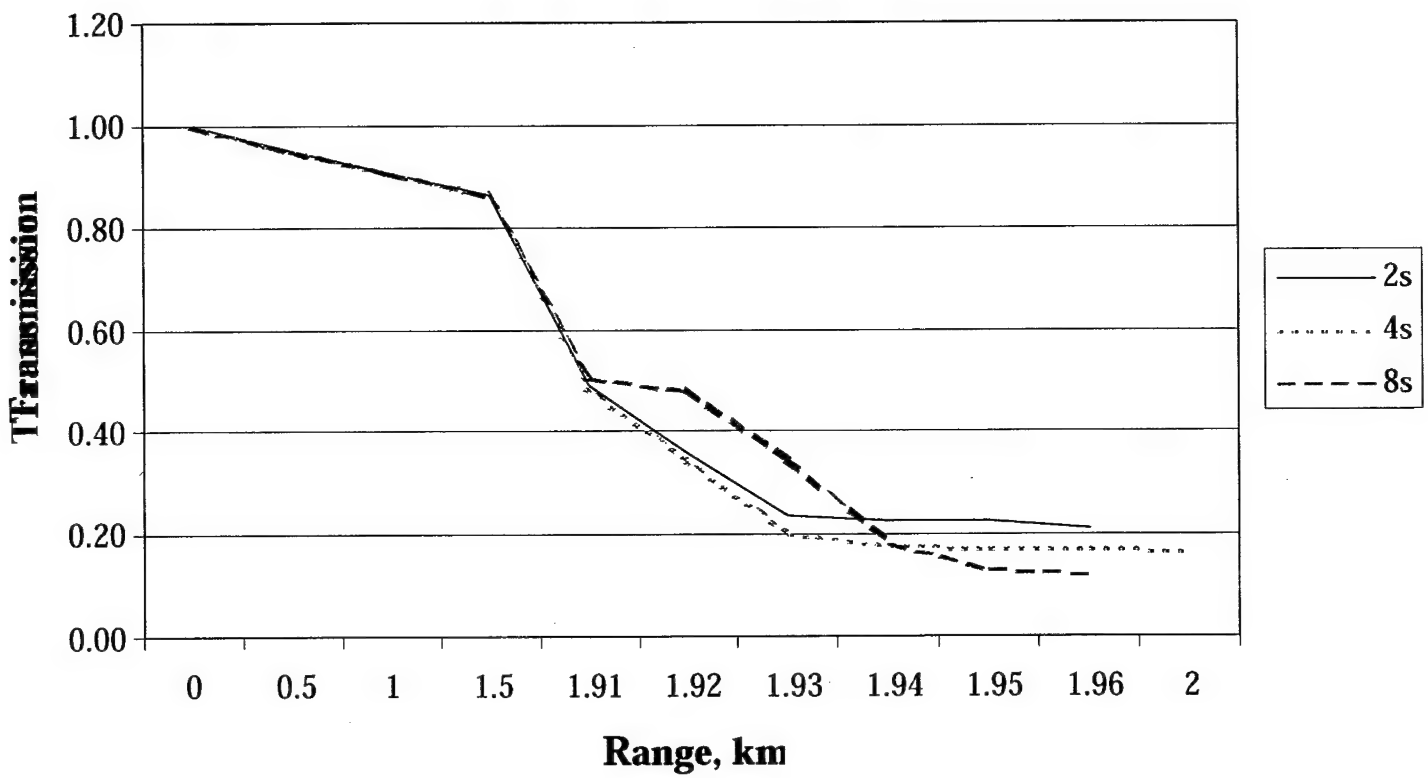
Acquisition Modeling

- **Multiple batch runs**
  - transmission for multiple times in obscurant event
  - cutoff at 30-32s; cloud begins to dissipate
- **Target used**
  - M1 type target, delta T 2 deg C
  - 1st generation FLIR for sensor
  - low clutter (M76), moderate clutter (L8A3) background
- **Extract results in Excel(TM) to view effects**
  - probability of detection (Pd) - wide and narrow FOV
  - can also model classification, recognition, etc.
  - graphical portrayal of Pd, range, time requirements

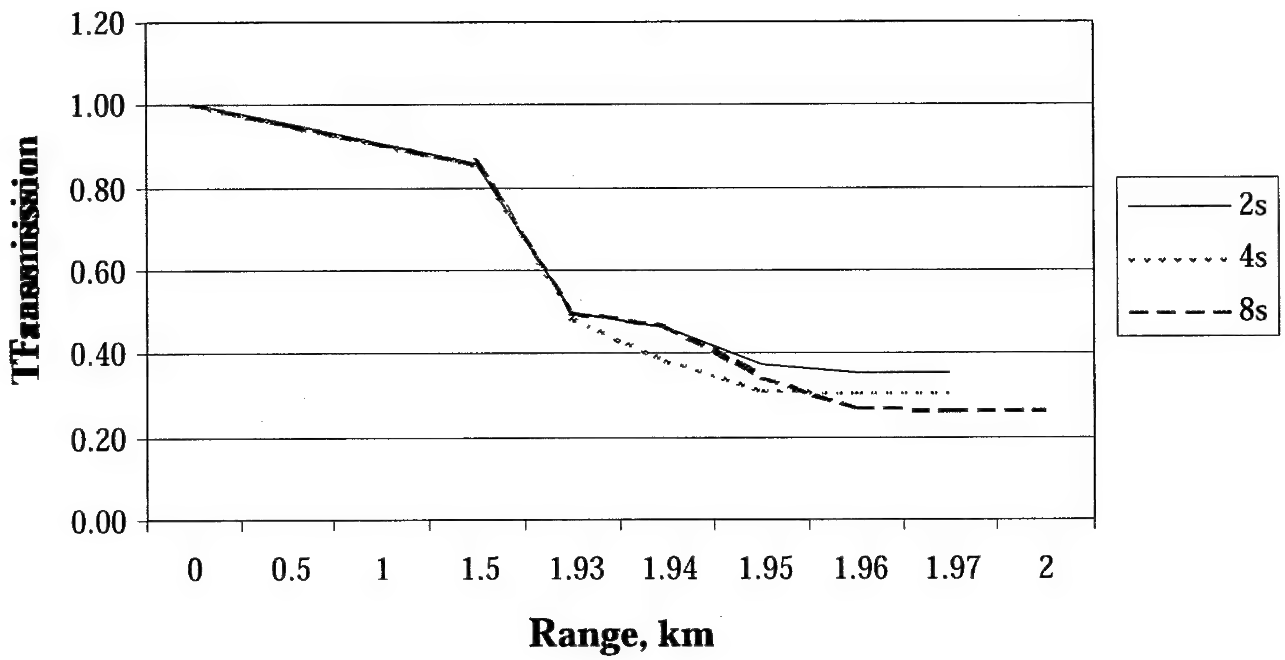
Results

- COMBIC transmission along target - observer LOS
- Pd - range relation for materials used
- Search time - range relation for selected probability

Transmission on LOS: 6 M76 Grenad



Cloud Profile on LOS: Mixed Salvo of 6 M76/L8A3 Grenades



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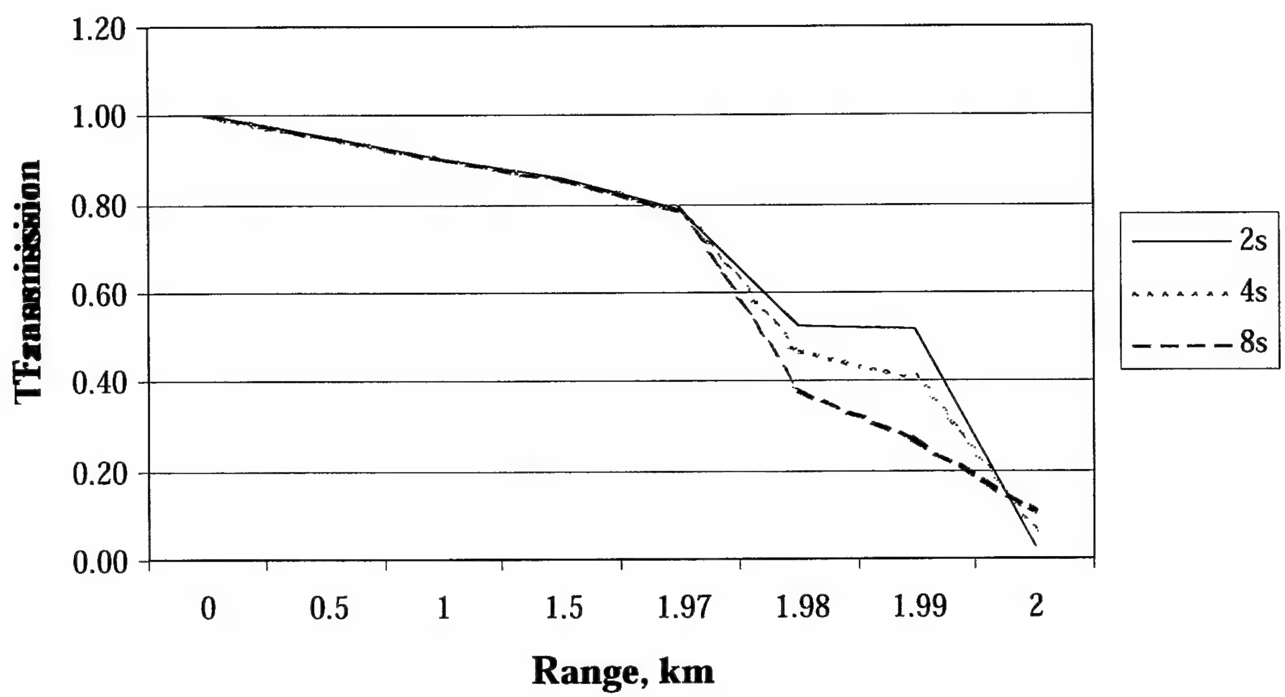
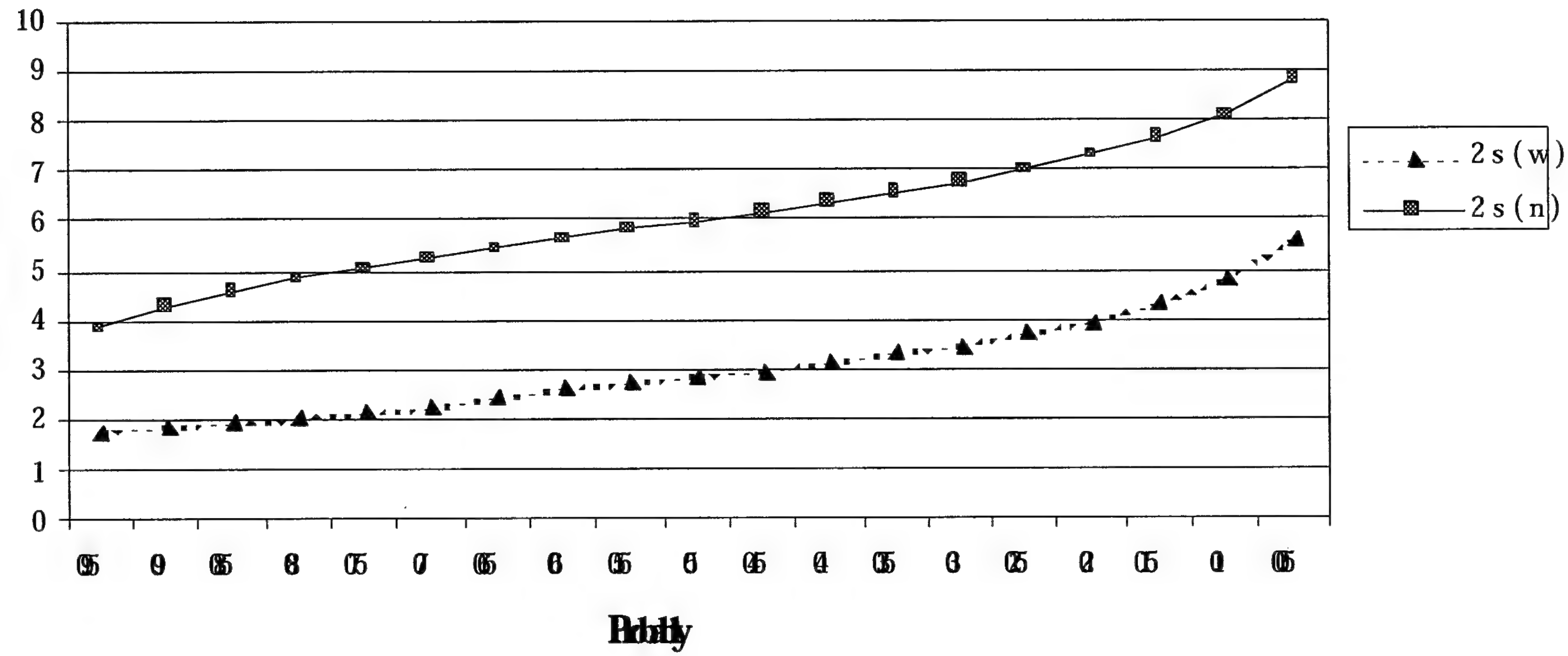
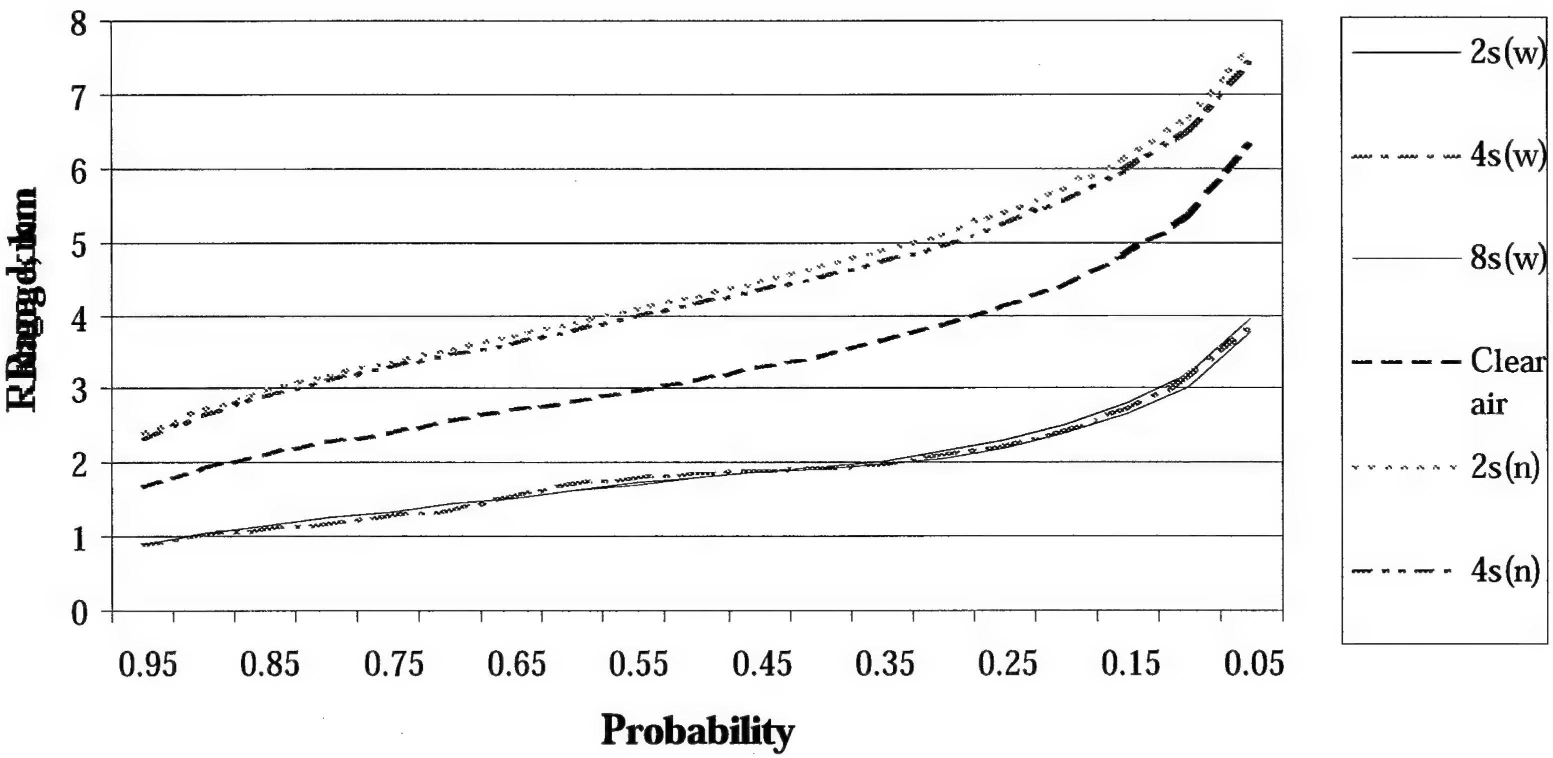
Transmission Profile on LOS: L8A3 Grenades (6) and Vehicular Dust



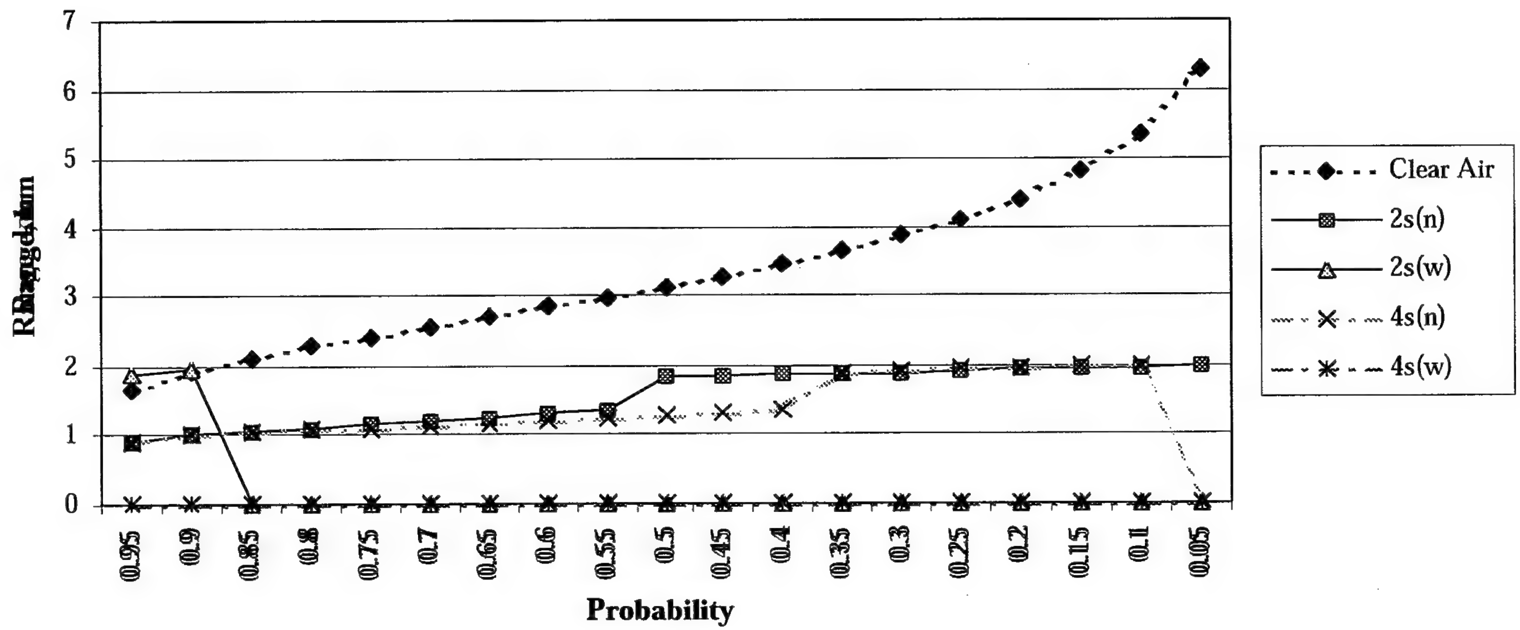
Probability of Detection, M766 Grenade Salvo



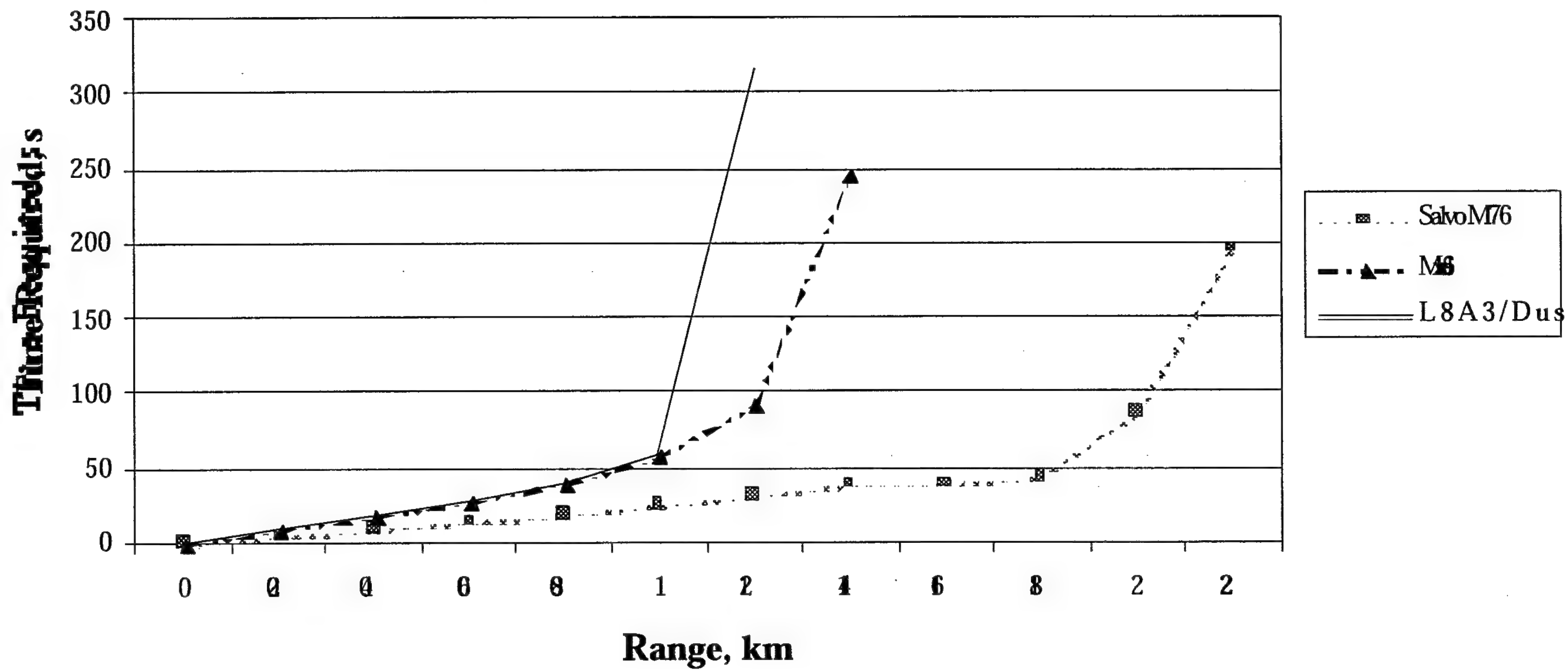
Pd, Time after Detonation, Mixed Salvo



Probability of Detection, L8A3 Salvo/ Vehicular Dust (Wide/Narrow FOV)



TS earch, Pd of 70%



Conclusions

- Very feasible to link aerosol models and sensor model
  - input/output conditions
- Information in warfighter's needs
  - select theater, region, season, etc.
  - ground and air scenarios possible
- Aerosols can affect advanced sensors
  - attenuation portrayed
  - clutter (e.g., radiance) included by altering characteristics

Insights for Future

- Explicit modeling for clutter effects, scatter
  - Alteration of related properties not sufficient
  - Characterization of low, moderate, high clutter
  - Out-of-path scatter may be important if increased ranges used
- Increased automation
  - reduce operator inputs needed
  - more cases in given time
  - focus on relevance and interpretation of results
- Faster/better response to user/PM
  - Examine key conditions/environments
  - Focus on weapon system/sensor characteristics
  - Smarter results

EW TESTING LESSONS LEARNED

Paul H. Berkowitz, Executive Vice President
Electro-Radiation Inc.

Track: SOS/DST Tuesday 6/16/98

ABSTRACT

Electronic Warfare (EW) testing is one of the more challenging undertakings in the Avionics community. EW tests are typically fraught with a myriad of problems due to the inherent complexity of tests involving multiple vehicles, radars, data collection, and data processing, as well as the complex nature of Electronic Warfare itself. Electro-Radiation Inc. (ERI) has been at the forefront of EW testing for many years, from B-52 to B-2 and from F-101 to F-22. While it is impossible to prevent all problems, it is possible to prevent the same problems from repeating. This paper applies many of the lessons ERI learned from its extensive EW testing experience, and offers recommendations of how to avoid repeating them.

1.0 INTRODUCTION

Electro-Radiation Inc. (ERI) has been a leader in the field of Electronic Warfare (EW) testing for many years. During this time, it has been seen that the complexities of EW testing create an enormously challenging environment. A typical EW flight test involves multiple aircraft, both jammers and victims; ground test radars; ground reference radars; airborne reference radars; a central facility for real time flight and test control; telemetry and displays for real time observation; data collection; post data processing to generate error information; a laboratory to test and program the EW system, with associated signal sources, meters, scopes, monitors, test boxes, reprogramming tools, and spares for emergency repair/rework; and a classified work area with data storage for manuals and test data.

For any single day's test, as many as 50 people from several Government agencies and contractors can be involved. In the center of this is the EW tester, who has responsibility for about 100 variables and control of perhaps 3. Given this complex scenario, it is not surprising that many problems arise. It is virtually impossible to run such an enterprise without problems. However, there are several problems that tend to occur quite often. It is these "repeat offenders" that can be eliminated fairly simply, with some careful foresight and planning. This paper presents several of these problems, and recommendations of how to eliminate them in the future, with the benefit of ERI's years of EW test experience hindsight.

There are several areas where issues arise in EW testing. These include:

- AIRCRAFT
- RANGE
- TEST
- DATA

2.0 AIRCRAFT ISSUES

When a new piece of equipment is installed in an aircraft, it must be integrated both physically and functionally. Most aircraft issues are related to the physical equipment installation. Functional integration usually proceeds fairly smoothly, since it is possible to test most interfaces with the actual equipment or a software simulation of that equipment. Most problems arise when the physical interface is different on the aircraft than in the lab, such as cable sizes and lengths; or when spatial functions, such as Direction Finding (DF) and sector crossover, are being tested for the first time.

2.1 Cabling

When Line Replaceable Units (LRUs) or "black boxes" are tested in the laboratory, they are usually placed side-by-side on a bench or fixture, with relatively short interconnecting cables. When those same LRUs are installed in the aircraft, they may be separated by tens of feet. Additionally, the actual cable runs may be much longer than that, due to connectors, bulkhead feedthroughs, etc. **Figure 1** illustrates these potential differences. A system that works perfectly on the lab bench, may encounter problems when installed in the aircraft due to the different cabling. Cable lengths can affect signal characteristics, such as timing, rise and fall times, driver loading, and voltage drops.

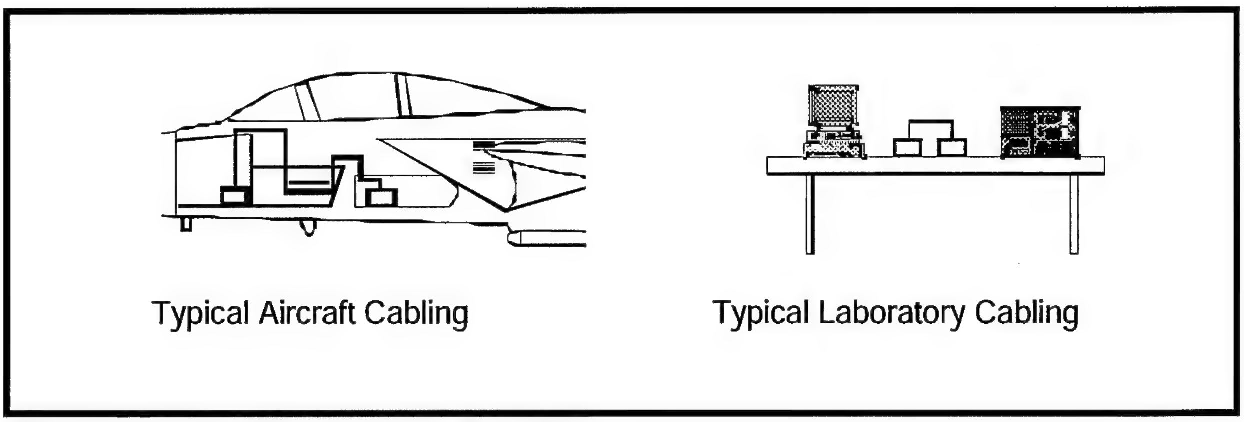


Figure 1 - Lab Cabling vs. Aircraft Cabling

Timing can create insidious problems, such as when blanking just fails to cover a potential interferer, and a sliver of undesired signal corrupts system performance. ERI experienced this during a B-52 EW flight test. A processor Line Replaceable Unit (LRU), or "black box" was installed near the crew station, and a direction finding (DF) receiver was under the nose radome. Because of the size of the B-52, the cable run was tens of feet long. The blanking signal to the DF receiver to protect it from seeing the EW system transmission was arriving just late enough to intermittently allow the interference. When the problem was finally diagnosed, it was easily fixed by adjusting the blanking signal timing.

Unexpected voltage drops can also create intermittent anomalies which can be extremely difficult to diagnose and correct. These problems are not limited to large aircraft like B-52s. A

recent ERI Global Positioning System (GPS) Interference Suppression Unit (ISU) test on a Falcon-20 business aircraft flights were lost due to an unexpected voltage drop in a DC power line. The line losses were enough to drop the +5 volts at the power supply down to +4 volts at the ERI LRU. To further complicate the issue, the voltage was high enough to enable ERI's system to turn on, but not high enough for the circuitry to function properly. Two flights were lost due to this problem.

The best solution to avoiding installed cabling problems is to use the same cables in the laboratory as in the aircraft. The simplest approach is to have two cable sets built for the aircraft, and use one in the lab. Then if any timing, loading, or loss problems arise, they can be solved in the lab. If schedule or cost considerations prevent using this approach, the next best option is to obtain the aircraft installation drawings and estimate the installed cable lengths and connections. Then a lab cable set can be built to the same design. Both of the examples cited could have been avoided had this approach been adopted.

2.2 DF and Sector Crossover

Direction Finding (DF) and sector crossover problems are very common in EW flight tests. Often, this is the first opportunity to actually radiate to and from the system, which is required to stimulate the DF and sector crossover functions. Additionally, this is almost always the first time these functions operate under dynamic conditions. To complicate the issue, there is limited control of the environment during flight test, making analyses, diagnoses, and correction difficult. Finally, aircraft installation can also affect performance, due to alignments, blockages, reflections, etc. These problems are very difficult to troubleshoot in flight. The true data reference requires accurate position, heading, and attitude data for the aircraft. Correlating the on-board (DF) data with the off-board (true) data is a data processing challenge. Additionally, there is very limited, or no, real time observation of the EW system possible during operation.

There are three parts to the answer for DF and sector crossover issues. Each solution has merit on its own, and applying all three is ideal. The first solution is to place the system in an anechoic chamber in the laboratory. The chamber does not have to be huge, or super "quiet". It need only fit the relevant Black Box with its antennas and radomes, and be large enough so that both the system antennas and test antennas are operating in the far field. The isolation must be enough to ensure personnel safety, and prevent interference with other lab activities. This will enable radiating tests with controlled conditions. Real time observation of all parts of the EW system is feasible, and correlation between measured DF and true data is simplified. Additionally, a full set of laboratory diagnostic equipment should be available with the design experts on call. The DF and sector system performance can be isolated from aircraft installation effects, resulting in a well defined performance baseline prior to flight test. Dynamic testing is somewhat limited, but even that can be simulated to some degree by programming a threat generator to "fly" through a defined scenario.

The second solution is to test the system installed in the aircraft in the Benefield Anechoic Facility (BAF) at Edwards Air Force Base. The BAF houses the largest anechoic chamber in the world as shown in **Figure 2**. It measures 264 x 250 x 70 feet and can accommodate virtually any existing military aircraft. The Radar Absorbent Material (RAM),

shielding, and free-space volume provide an ideal test environment, free from interference, with repeatable test conditions. It includes an 80 foot diameter turntable which can rotate over

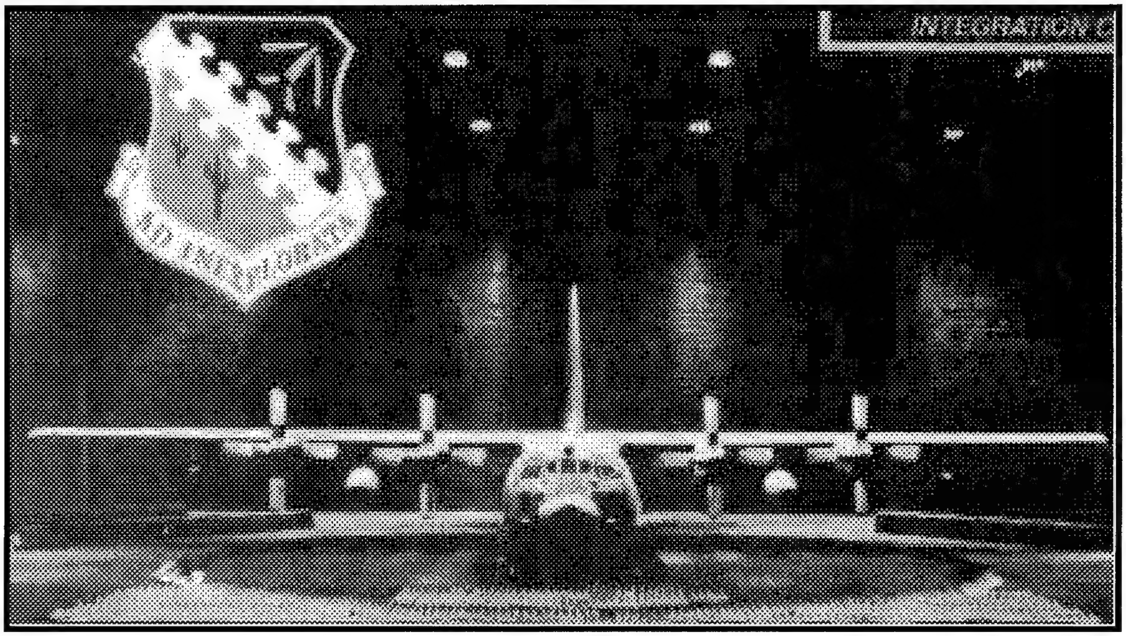


Figure 2 - Benefield Anechoic Chamber

250,000 pounds, ±190°, with 0.05° resolution. This enables DF and sector crossover testing of the installed system in a controlled environment. Untold hours of flight testing can be eliminated by judicious use of the BAF.

The third solution is to develop a "walkaround" aircraft tester. This can range from a formal piece of flight line test equipment, to an informal cart full of laboratory test equipment and an extension cord. While the aircraft is on the flight line, DF can be evaluated on the installed system by radiating from the cart to the aircraft from previously marked angle positions. This enables limited DF troubleshooting under static, but installed conditions. The set-up is less than perfect, since there can be multipath from the ground or nearby structures. However, careful selection of location, coupled with a few panels of RF absorber material scattered on the ground between the cart and the aircraft, can all but eliminate the potential interference. A fringe benefit of such a test set-up is that it can be used for a confidence check prior to each flight test. Before takeoff, the installed system can be verified to be receiving and transmitting properly, before costly flight test assets are committed. It was the assembly of such a walkaround test cart that enabled the diagnosis and fix of the aforementioned B-52 DF blanking problem.

3.0 RANGE ISSUES

In order to evaluate Electronic Warfare performance, specialized test ranges are required. These have the necessary threats and threat simulators, as well as physical security to enable uncompromised classified testing. Due to the assets and physical spaces required, there are a

limited number of ranges available. As unique as each is, they all tend to suffer from the same issues, driven by threats, scenarios, multipath, and new threat assets.

3.1 Threats

The categories of threats that are typically encountered during EW flight testing include:

- Surrogates - Friendly systems used in place of real threats
- Simulators - US build replicas of real threats
- Real Threats - Actual threat systems

Each of these have potential problems which must be addressed.

EW systems are usually designed against a formal list of threats defined at the start of the program. These threat parameters are used to define threat identification tables, algorithms, etc. Although the EW systems are reprogrammable, the baseline programs are based on the defined threat data. If the systems encountered during testing are not consistent with the real threat data, the EW system will not be able to perform properly, and test results can be severely impacted.

Surrogates by their very nature are not likely to match the real threats in all categories. They may have parameters outside the real threat ranges, waveforms different from the real threat, or modes different from the real threat. Even when these are identified, they can be difficult to solve. An EW flight test was run using an F-106 as a surrogate for a Soviet fighter. The F-106 radar had a PRI modulation not present in the real threat, therefore the PRI modulation circuit was disabled. The EW system detected modulation and made the wrong identification (ID). The EW system engineer met with the radar manufacturer's representative, who showed the schematics, and the capacitor which coupled the modulation which he said he removed. Out of frustration, the EW system engineer requested the removal of the radar unit from the aircraft for inspection. Luckily, the field rep was not insulted by the request and did so. The radar unit was opened on the radar test bench, and sure enough the capacitor was removed. Power was hooked up to the unit so the circuit output could be seen. The capacitor was replaced, and the PRI circuit exhibited the modulation. The capacitor was then removed and the PRI exhibited more modulation than before! Since there had never been a need to remove the modulation, the underlying signal had probably never been examined before. With a simple modification the circuit was connected to a crystal, creating a PRI signal which matched the threat. From then on, the EW system ID'd perfectly. Only because a junior engineer was naive enough to ask to see for himself, and a senior field rep was kind enough to indulge, was this problem discovered and fixed. (I am to this day grateful to him.)

Simulators may not match the real threats because they may have been built using older threat data, using current data but from a different intelligence source than the EW program data, or they may have been modified since original design. Even real threats may not match program data, since the threat systems may be aligned to extremes or have substitute repair parts which create signals outside the defined ranges. Simulator and threat alignment has often been a problem for EW system testing. In at least two cases of real threats ERI has been involved with, the alignment procedures developed by the US operators went far beyond the radar manual instructions. Both examples had defined alignment procedures which were difficult to implement and could drift with time. They were replaced with new procedures which were really only

applicable to test conditions and could not have been used in the field, but significantly increased the radars resistance to jamming. This put the EW systems at an artificial disadvantage during testing against these two threats. Even worse, in both cases it was EW engineers who showed the radar operators how to better align the systems! As Pogo said - we have met the enemy and he is us.

The solution to all of the above potential problems is the same - measure and verify each threat system on the test range that the EW system will encounter. This requires getting portable equipment into the field, to measure and record all critical parameters, such as frequency, PRI, jitter, pulse width, etc. The recorded data can then be used to program signal generators in the laboratory in order to test the EW system with the test range threats. The EW system can then be modified for operation with the test threats. This may include reprogramming threat ID tables, modifying threat lists, and/or adding a TEST mode for test range threats only.

3.2 Scenario

Most EW tests are planned to include a limited number of threats at any given time. **Figure 3** illustrates a typical planned scenario. This enables easier interpretation of results when initially working one-on-one, and holds down range costs. After the individual tests, one-on-many tests are run to ensure operation in a realistic environment.

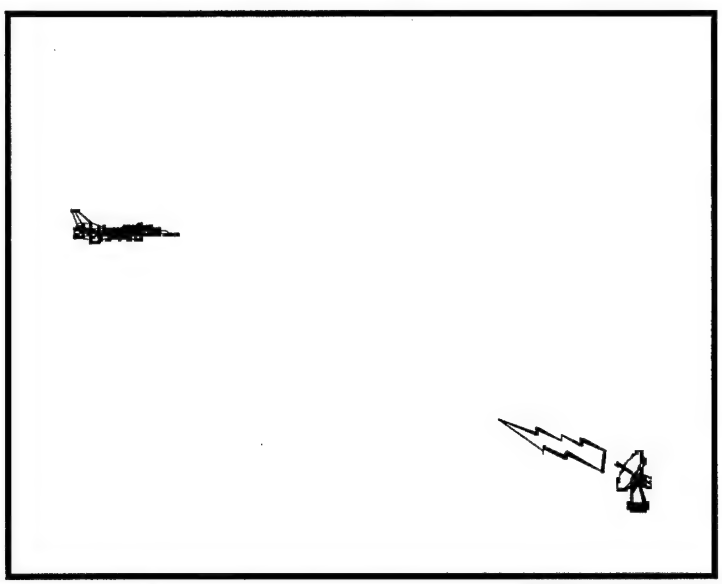


Figure 3 - Typical test scenario planned

The potential problem is that the range assets are not always totally controlled. Test sites may be transmitting for maintenance or calibration. Operators may want to track a target of opportunity for practice. If the aircraft is a low observable (LO) vehicle, it is very tempting for an operator to try to detect it. Another possibility is that there may be other tests going on within the radar horizon. Even large test ranges have limited airspace, and there are usually co-located or nearby bases flying routine training missions. ERI has found that at a typical EW test range like Eglin Air Force Base there are always F-15s flying nearby, creating a nearly continuous

high pulse density background. Again, in the case of an LO vehicle, there is the additional temptation for them to try to find and track it. The bottom line, is that despite the best of intentions, the scenarios encountered are usually outside the test plan as shown in **Figure 4**. This can impact the testing by tying up limited EW system resources on non-test signals and which can bump test threats from limited EW system resources, resulting in a form of unexpected interference.

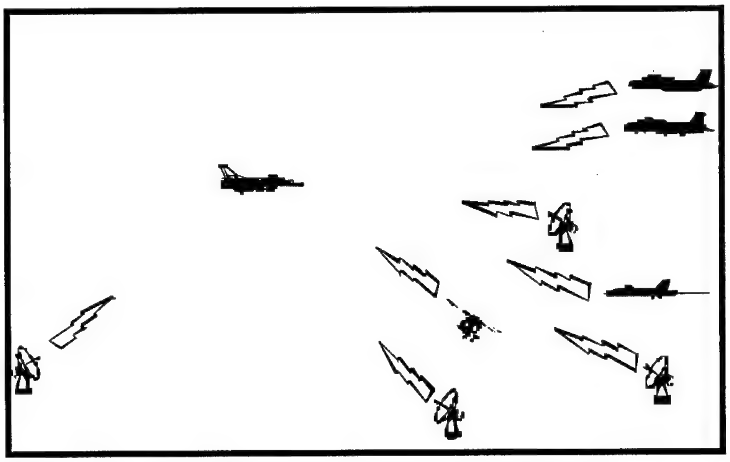


Figure 4 - Typical test scenario encountered

The solution to scenario issues is similar to the threat issues - identify the potential problems and solve them in the lab before getting to the test range. Identify all the threats on the test range, to provide definition of possible unintended signals which may be encountered during testing. This includes ground assets and locations, airborne assets, and nearby air and naval assets. Then program the laboratory signal generators with the potential unintended signals. Layout the ground sites the same as they are on the range and add in a mix of on- and off-range airborne signals. This will enable evaluation of the worst case likely to be seen on the test range.

3.3 Multipath

Another form of unintended signal corruption possible during flight test is multipath. During low altitude flights, both received and transmitted signals can be reflected off the ground and added to the direct path signal. This distorts the signals in both directions, by adding time varying amplitude and phase modulation, and stretching the pulse width. This can impact threat identification and jamming. Pulse width threat ID can be affected, and any retrodirective jamming techniques can be corrupted by the multipath AM and PM. In early B-1A monopulse EW flight tests conducted by ERI personnel at 200 feet, the effects of multipath were disastrous. It took multiple flights to solve the problems. Fast forward 15 years, and a B-52 EW flight test at 500 feet suffered many similar problems. ERI was called in to assist, and not surprisingly, the same solutions installed in the B-1A EW system, were implemented in the B-52 EW system, and the multipath problems were again solved. Despite the reputation of B-1 EW, it saved the day for the B-52.

Since multipath is a physical phenomenon, it cannot be eliminated. If required to fly at low altitude in the real world, the EW system must be able to work in the presence of multipath. The solution is to simulate multipath effects in the laboratory. The effect can be calculated for the planned flight geometry. Multipath can be created in the lab by coupling a sample of the signal with the anticipated delay and reflection loss. Adding random amplitude and phase modulations increase the fidelity of the multipath simulation. Typical EW system modifications to enable operation in the presence of multipath include adjusting pulse sampling times, adjusting measure and set update rates, and stretching jam pulses to cover the delayed reflection.

3.4 New Assets

One problem that seems to reoccur in EW testing is when the system is scheduled to be the first to test against a new threat asset. Although it should not matter, ERI has found that the first test against a new asset tends to be very inefficient. There is usually more time spent troubleshooting the threat asset than testing the EW system. Additionally, the lack of a threat performance baseline creates difficulty in interpreting results. ERI's experience dictates that the first test on an asset always takes longer than planned.

There are no real solutions to this potential problem, but there is a way to minimize its impact. The best option available is to schedule the new asset at the end of the EW system test sequence. If there are problems with new asset, the impact to the other tests is minimized. If the test cannot be completed within schedule, it will likely be necessary to cancel or postpone the new asset test. If postponed, the return may be after the asset has matured, eliminating the problem.

4.0 TEST ISSUES

Due to the complex nature of Electronic Warfare evaluation, the test process itself, has many issues. These include EW system configuration, operator learning, operator cooperation, and operator observations.

4.1 System Configuration

The two primary potential problems are the risk of uncertainty in EW system parameter settings and multiple EW setting changes between test runs. System changes are often made between test runs in order to maximize the amount of data during a flight, especially during optimization and development testing. Under short time and intense pressure, it is easy to forget to record the details. This can later cause chaos during data analysis, when it may be difficult to recreate the information. This creates obvious challenges in interpreting the test data. The second problem is caused by changing multiple settings between runs. If performance gets better (or worse) it is difficult to determine which of the multiple changes (or combination) was the cause.

The solutions for both are essentially to adhere to the discipline of good test engineering practice. In order to insure that an accurate record of system settings and events is recorded, ERI

assigns an individual, who is outside the decision making loop, the full time task of religiously recording all pertinent data. This includes start and stop times of all runs, all system parameters for each run, and any observations or contemporaneous comments made by any participants. This will insure a complete and accurate record which becomes invaluable during data analysis. In order to prevent ambiguous results, a similarly disciplined approach to system changes is required. ERI assigns the final say for real time changes to a single individual for consistency and to maintain control for the test discipline. He is tasked to limit changes to a single parameter between runs, and also to attempt to bracket a good setting to establish confidence that it is optimum.

4.2 Operator Learning

EW versus automatic systems is a waveform versus processing battle, which typically provides very consistent results. If it works, it will work over and over again. EW versus a human operator is more a battle of wits, because the human operator learns every time he sees the EW waveform. Since the effect is one of deception, surprise is a large part of the success. If the human operator is given enough time, eventually he can discern even trivial clues which he can use to negate the deception. For example, if the EW system uses a cover pulse, a wide noise pulse to cover the real target return, it can prevent accurate range tracking. Additionally, this will create a situation where the radar angle tracking circuits only see jamming, with no aircraft skin signal (this is known as an infinite Jam-to-Signal ratio), enhancing the chances of angle errors or breaklock. But since the cover pulse frequency will not be exactly the same as the radar frequency, the two frequencies will beat against each other, creating a "birdie" where the real target is. This can be masked but not eliminated. Given enough time, a radar operator can eventually learn to isolate the birdie. Another subtle but potentially useful cue is when the baseline lifts slightly under a false target which covers the real signal. This is known a "the mouse under the rug".

There are two aspects of EW testing that make the process vulnerable to operator learning. First, although simulation and analysis can direct the system designer towards effective jamming techniques, the final optimization requires repetitive runs to home in on the best waveforms. This can give the operator an opportunity to observe the techniques many times, and try various means of countering them. Although an operator in a real situation would only see a technique once, the test operator has multiple opportunities to learn. If a minor cue in a technique can be learned, the remaining test runs can result in zero effectiveness. This can clearly skew test results in an unrealistic and unfavorable manner. Second, the statistical requirements to establish confidence in the test data require multiple runs of the final jamming techniques. This further extends the operator learning opportunities, but can also present a situation where the aircraft geometry is the same run after run. Operators learning the target aircraft location can further bias the test results against the EW system.

Operator learning can never be totally eliminated, but it can be minimized. The first step is to limit operator exposure during optimization tests. This can be accomplished by utilizing a limited subset of available techniques during the optimization phase, ideally the lower priority techniques. When the data testing begins, the operator will be faced with previously unseen techniques. To minimize operator learning during the data runs, techniques with some

randomness should be employed. For example, if using false targets, randomize the position of the real target from run to run. If using multiple techniques with equivalent effectiveness, also randomize selection of the technique for each engagement. Finally, plan the data test flights so that different aircraft geometries are interleaved rather than running one geometry repetitively.

4.3 Operator Observations

One of the data sources available during EW flight testing is the observation of the threat operators, both ground and air. However, if taken as gospel, these observations can create problems. Operator reports may favor their systems. The operators have pride in their systems and aircraft, and the adversarial nature of the tests stimulate operators competitiveness. Therefore, operator reports are susceptible to an unintentional bias against the EW system. Additionally, the best jamming techniques are surreptitious. The system may be indicating to the operator that all is well, when it really isn't. For example, a pilot may be maintaining a steady track, but it might not be on the real target. There are many examples of fighter pilots reporting "I had him all the way and could have foxed (fired a missile) at any time", when later data analysis indicated it was a side lobe lock that had the antenna pointing in the wrong direction, where a missile firing would only have resulted in a wasted missile.

The solution to these potential problems is threefold. First, verify and validate all operator observations during data analysis. If the data confirms the observation, the confidence is increased. If the data refutes the observation, this is also valuable information, since it can provide insight to how a real operator will interpret the jamming effects. Second, deploy test personnel to observe at radar sites. They can not only provide independent observations, but can also learn from watching the displays and the operator actions. For airborne threats, the cockpit displays should be videotaped, with contemporaneous comments from the pilot also recorded. Third, the test personnel should conduct thorough crew debriefs. Ask about specific cues that led to any observations. Get as much detail as possible to understand the operators thought processes in the face of the jamming.

4.4 Operator Cooperation

EW testing often uses US systems as surrogates for foreign threats. Generally this requires restricting the radar system operating modes which are beyond the real threat capability. This can tempt operators to sneak a peek at the forbidden settings. Being human, the operators are often both curious and competitive. They will sometimes try a restricted setting, especially if the jamming is successfully defeating the limited modes. If they do try, they often won't admit to it. This can corrupt optimization and/or data collection.

A solution that ERI has employed in the past with very good success is to dedicate one run per day for the radar operator. For that run he is allowed unrestricted free play for his radar. ERI programmed different techniques for him and provided assistance analyzing the data. This satisfied all operators curiosity and competitiveness, making it easy for them to stay within the restrictions for the rest of the test. This insured valid EW data collection, and provided the radar personnel additional useful data. It is a win-win approach that gets everyone on the same team.

Unfortunately, occasionally the competitive urge can go beyond normal behavior. ERI was involved in a helicopter EW test which successfully employed many of the operator learning defenses described previously. When the data runs started, the operators were caught by surprise and the EW system performed very effectively. Apparently the lead radar operator assumed nothing could beat the radar, because he called an immediate halt to the test so he could re-calibrate the radar. After calibration, the test resumed with the same good EW system performance. This was just too much for him. He opened one of the radar system drawers, and started adjusting the radar servo loop, while the jamming was present, dampening the response to the point where the EW system could no longer drive the radar off the helicopter. At that setting, the radar could not track anything but a slow moving helicopter and was clearly an egregious violation of fairness for the test. The Army project manager witnessed these actions first hand, and said to the radar operator "you can't do that." He replied, "Lady, it's my radar, I can do whatever I want." Fortunately that is a rare occurrence, but it highlights the extremes of human behavior that the competitive nature of EW can cause.

5.0 DATA ISSUES

EW tests tend to generate a lot of data. Very often, millisecond type events must be obtained from data steams running for minutes. The problems stem from the nature of the data - digital rather than analog, and the turnaround time required to reduce the data for analysis.

5.1 Analog vs. Digital

The preponderance of data generated in EW flight testing is digital. All EW systems are under computer control, many of them including distributed microprocessors. Therefore, virtually all of the data generated is digital. Analyzing digital data can be very time consuming. It is difficult to scan thousands of lines of data looking for correlated events without automated routines. The high sample rates are required to capture all the events, producing the volumes of data. Lower sampling rates could reduce the amount of data, but at the risk of missing significant events. Alternatively, analog data paints a picture of the events, enabling rapid insight into events. **Figure 5** illustrates the advantages of analog data for a quick "big picture" look over digital data.

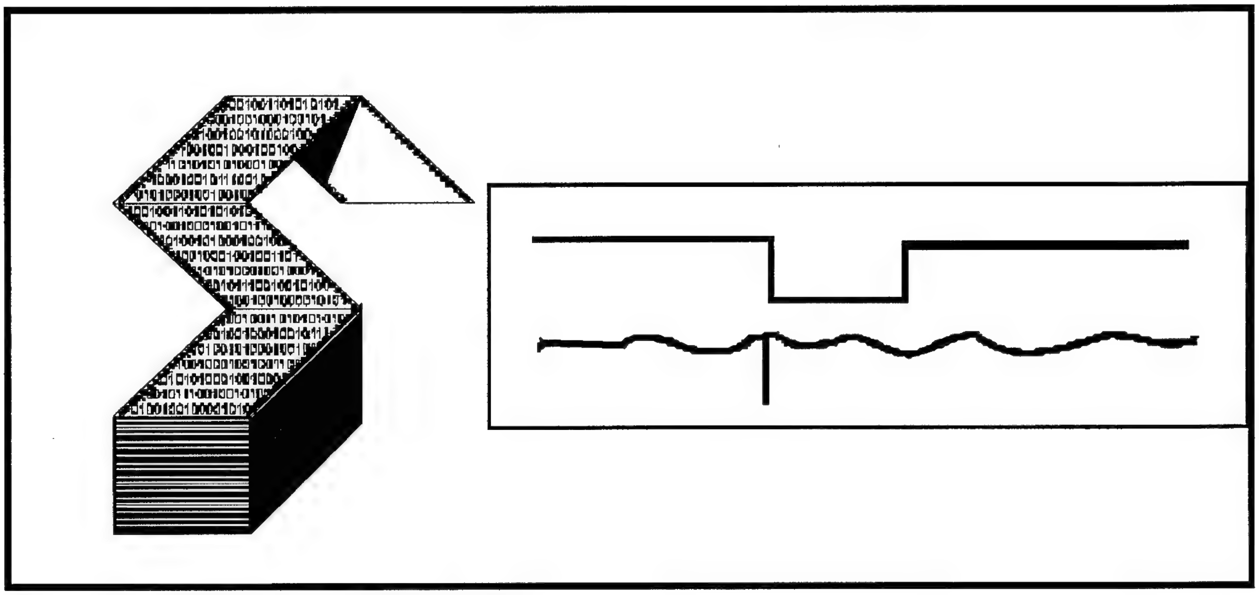


Figure 5 - Analog versus Digital Data

The primary solution obviously is to generate analog data. This can be done at the recording site, by adding analog recording channels to capture critical data such as received power level (envelope detector) and transmitted power for each jamming channel. Alternatively, this can be produced by post-processing, to generate analog reports from recorded digital data. Having key data in analog form can enable quick look analyses of entire runs in brief scans. The human eye and brain can process analog data virtually instantly. A secondary solution is to filter the digital data for volume reduction. Collect the data at the required high sampling rate, but print out only when selected parameters change. This will eliminate several hundred lines of identical data which must be carefully scanned to find a single parameter change which may be meaningful.

5.2 Turnaround Time

The high volume and complex nature of EW test data can result in long turnaround times. In the worst case, it can exceed the time between flights. During optimization or troubleshooting efforts, this can be a disaster. Data turnaround times can reach a week, while flights can be scheduled three times a week. It is difficult to plan Monday's flight when the previous data arrives Friday. ERI encountered exactly this situation during a B-52 EW test. Schedule demands drove the test to 3 flights a week, but the data reduction facility was working on a 6 day turnaround.

The ideal solution is to interleave threats on the schedule, so a given threat won't be repeated until after the previous data is available. However, this is often not practical. In that case, it becomes necessary to generate critical data products by hand from immediately available data. Examples include hand drawn strip charts from viewing cockpit videos, and hand drawn strip charts from unfiltered on-board digital printouts. These can be correlated via time, since all recordings include a common range clock, usually Greenwich (Zulu) time. Although this is not a replacement for end product data analysis, it can provide enough insights to make some educated assessments for the next flight.

This is exactly what ERI did when the B-52 test schedule got frantic. F-15 cockpit videos were run frame by frame, and significant events were recorded by hand. **Figure 6** illustrates the eclectic mix of technologies used to solve this problem.

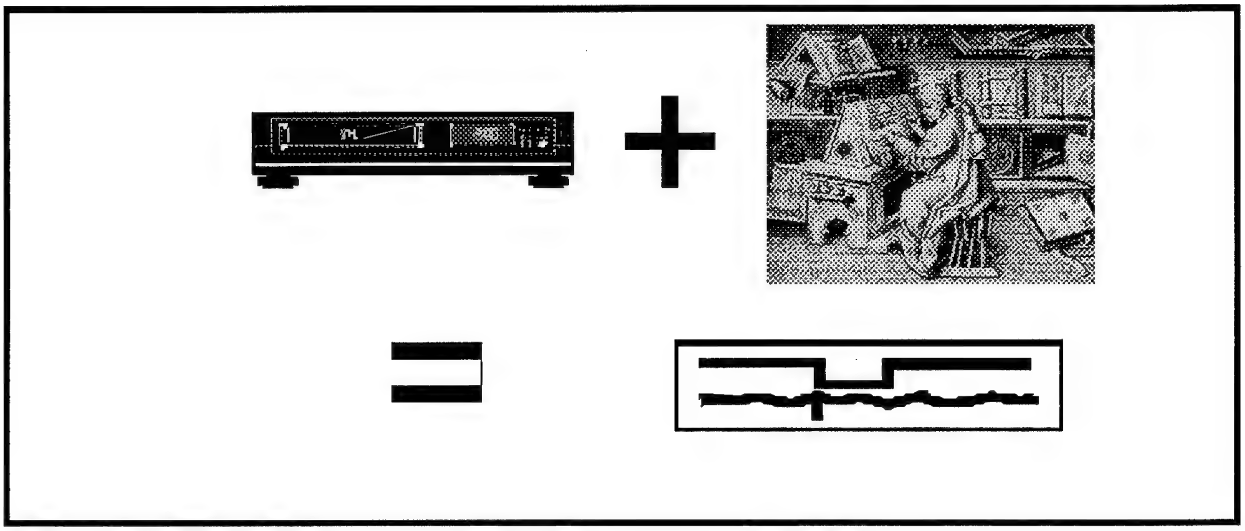


Figure 6 - Technologies employed for data turn around solution

The video radar data included changes in velocity, range, azimuth, or elevation. The digital system data recorded on the aircraft was printed by Boeing as soon as the aircraft landed and overnight expressed to the test range. The data volume had been reduced by the selective print out technique, and was analyzed for critical events. Finally, strip charts were manually created from the two data sources. The alignment of the data from the two sources was verified by correlation of the EW velocity jamming and the F-15 velocity readout. It provided enough information to make educated decisions for the successive flights, until the full data package could be reduced and analyzed.

6.0 SUMMARY

Electronic Warfare testing provides many challenges and is fraught with dangerous problems. Fortunately, many known problems can be anticipated and avoided. If a real estate agent's secret to housing is "Location, Location, Location," ERI's secret to EW testing is "Plan, Plan, Plan." Yet despite the best laid plans, there will be problems. One of the strangest of these involved a recent helicopter borne EW flight test at Eglin. A couple of weeks were lost due to an aircraft accident. The helicopter was hit while it was parked on the flight line - by a lawnmower! Even worse, the driver couldn't be arrested - he was already a prisoner at Eglin's Club Fed!

The bottom line is there will be problems, that is guaranteed. However, with foresight and planning, at least they won't be the same old familiar problems.

Environmental Sensing As An Input To Stockpile Reliability Management

William W. McAdam
Senior Engineer, R/M/S/T
Northrop Grumman Corp.
Electronics Sensors and Systems Group

Track:

Joint SOS - Simulation, Test, and Diagnostics

Abstract:

All stockpile reliability management concepts are based on a model of the performance of the hardware under storage and handling conditions. Due to recent trends in technology, the stockpile reliability manager is now able to understand what series of environments each unit has encountered. He can then apply that information to his model to determine more accurately what amount of wearout the unit has accrued, and, hence, what 'life' it has remaining.

This paper discusses:

1. Various methods of applying environmental sensing and data recording (ESDR).
2. Appropriate levels of assembly for application of ESDR, hardware limitations on ESDR, and trades that have to be made when applying ESDR.
3. How ESDR impacts stockpile reliability management processes and staffing.
4. How recorded information can be applied to management models
5. How applying ESDR data to hardware models improves stockpile reliability management.

8/19/98
Wm. W. McAdam

1.0 Maintenance Structures Are Predicated On Models Of The Hardware

All maintenance structures are based on a model of how the hardware to be supported reacts to the various environments that it is expected to encounter while in storage and in use. The most common approach to stockpile management is to assume that environments are evenly spread throughout the life of the hardware and that the remaining time to wearout and disposal has, therefore, a linear relationship to the age of the hardware. However, the amount of wearout that each individual item within a stockpile has incurred is, in reality, a function of the accumulation of stresses induced by environments that occur randomly during the usage storage/profile that system has seen. By sensing and recording the environmental conditions or extremes seen by each stockpile element and applying that information to the stress model of that system, the stockpile manager can determine where that unit is in its designed for life. Utilization of environmental data in this manner represents a significant refinement in prognostic capability for the stockpile reliability manager.

2.0 General Rules Regarding The Application of ESDR

Environmental Sensing and Data Recording (ESDR) can be applied at any level of assembly within a system, and provides the capability for significant improvements in the system's support concept. In addition to providing inputs to the stockpile manager's data engine, ESDR can improve the overall support concept by providing significant reduction in retest Oks (RTOKs). This is made possible by providing the stockpile manager with information regarding the conditions (environments) under which failures have occurred.

Tailoring ESDR to the system involves trades being made between the cost and complexity of the ESDR hardware/software and the burden placed on the support system. Later sections of this paper will discuss specific trades to be made when applying ESDR at various levels of assembly. ESDR must be applied using the following general guidelines:

- The decision to incorporate ESDR into a system's support concept must be made on the basis of the optimization of life cycle cost. There will be an increase in acquisition cost associated with the addition of ESDR to the support concept, but a trade must be made to determine if, in the case of that specific system, the increase in acquisition cost is justified by the improvements in system support costs, operational availability, etc.

- ESDR applied at any assembly level must be capable of sensing and recording environmental data applicable to each constituent removable item from that level. This information need not be sensed at the lowest level of assembly, but a transfer function must be available from the point of sensing to the removable item. That information could include any combination of the following environmental characteristics: Temperature, Temp. Shock, Vibration, Humidity, Power Spectral Characteristics, Stress/Strain, Mechanical Shock, Coolant Flow/Pressure, etc.
- Data recorded by ESDR must be in a format that makes it applicable to the model of the hardware, within the limitations imposed by the installation. In some cases, a time histogram of the environments experienced is necessary, whereas in other cases it may be sufficient to simply record occurrences of periods of overstress.
- ESDR hardware must be inherently higher quality than that of the hardware which it is to support. That is because it must operate in environments that the supported hardware must only survive in storage, making its storage and operating environments the same.

Environmental Sensing and Data Recording is most commonly a microprocessor based monolithic device incorporating, as a minimum, a serial digital external interface for data communication and control, accelerometers for vibration/shock sensing, thermal sensors, and an autonomous power supply.

3.0 Application Of ESDR At Higher Levels Of Assembly

Addition of ESDR at the highest level of assembly (the system level) is desirable for a number of reasons. ESDR can most easily be added into a maintenance structure for systems that have already completed design and are soon to be or have already been fielded at the higher levels of assembly. The addition of ESDR hardware at the system level requires little or no redesign of the actual system hardware if the system is maintained as a 'wooden round' or is maintained in a multiple level maintenance concept. In a traditional three level maintenance structure, system maintenance is accomplished by exchange of large Line Replaceable Units (LRUs), made up of smaller assemblies that are repaired at depot or contractor facilities. Adding ESDR to the LRUs is usually nothing more than adding an assembly populated with a single self contained ESDR capability to each LRU. This assembly can be placed into system real estate generally devoted to hardware growth capability.

Since ESDR hardware stays with the LRU as assemblies are removed from it and replaced by other ones to effect LRU repair, utilizing ESDR at these high levels of assembly places additional burden on the support system to track the accumulation of stresses and wearout experienced by each assembly as it moves from LRU to LRU. Addition of ESDR to the system level does not come without a cost, however. Batteries used power the ESDR package to allow it to autonomously sense environmental conditions must be recharged or replaced. If no automatic data link (either physical or by radio) is mechanized between the ESDR and a stockpile management control station, the maintainer must periodically visit each item in the stockpile and download the data to some portable media for transfer to the control station. Both of these represent an effective wearout mechanism for the hardware that did not originally exist. Additionally, the cost of the ESDR hardware (and its development) represents both a recurring and a non-recurring cost to system acquisition. However, the cost of incorporating ESDR at the system level is offset by reduction in requirements for periodic maintenance that come about because ESDR has been incorporated into the system. For instance, ESDR could be utilized to sense humidity within the storage container and transmit that information directly to the control station on a periodic basis. This function would effectively eliminate the need for a maintainer to periodically review the condition of the storage container by looking at a sight glass. A residual benefit would be that the failed item could be immediately scheduled for corrective action a soon as the out of tolerance condition was encountered, instead of the unit in storage being subjected to the out of tolerance condition until the next maintainer visit time in the IRAN cycle, which could be a significant period of time. This would serve to improve the quality of the hardware in stockpile, effectively improving its reliability to the user once it is pulled from storage and placed into use.

3.1 Application Of ESDR At Higher Levels Of Assembly - An Example

If, for instance, we determine in the design phase that the wearout of a hypothetical missile system is primarily a function of:

- The intrusion of water vapor into the missile container, contaminating the motor propellant
- Delamination of the propellant due to vibration and shock.
- Failures of the Guidance Electronics due to thermally induced stresses.

We might mechanize an ESDR device, tailored to the application that incorporates the following features:

1. Battery powered unit, internal to the missile container, capable of sensing humidity, incorporating accelerometers to sense shock and vibration, temperature sensor.
2. Since humidity, temperature, and vibrational stresses should not be very dynamic, the unit might be equipped with a 'sleep mode' and 'wake up' infrequently to sample the environment. Sampling might be done once per 4 hours if diurnal cycling were determined to be an issue, or as long as once every 2 days to a week if not. This feature would serve to minimize power consumption and memory utilization for environmental data storage.
3. Since shock environments are random, and short-lived, the unit might be equipped with a 'wakeup' circuit that is low power and provides an interrupt stimulus to the ESDR processor to wake it up in the event of a shock event. The threshold of the wakeup circuit shock sensor must be set such that the processor is not interrupted unless the wakeup circuit determines that he shock was of sufficient energy to be catastrophic in nature. A second wakeup circuit with a lower threshold would be incorporated into the ESDR design to wake up the processor in the event of detected vibrational or shock environments that are not considered catastrophic.

Items 2 and 3 would be incorporated to minimize power consumption and maximize battery life without compromising data fidelity.

4.0 Pros/Cons Of ESDR at The LRI Level

The most effective utilization of ESDR is at the lowest repairable level of assembly. However, addition of ESDR hardware to this level of assembly requires that the ESDR hardware be incorporated into the system from the onset of the design process in an integrated approach. ESDR incorporation into the Lowest Repairable Item (LRI) does not significantly affect the ability to record pertinent environmental data and associate it with the lower level assemblies. However, adding ESDR provides new functionality that serves to optimize the overall maintenance concept, thereby reducing O & S costs. A microprocessor based device installed on the LRI can be modified to incorporate P1149.1 or other testability interfaces to allow the ESDR device to participate directly in the BIT architecture. This dual use capability minimizes the real estate cost of the incorporation of the ESDR into the LRI by making it into an effective replacement for BIT related hardware. Additionally, the ESDR can be utilized as a repository for BIT test results as well as environmental data, both of which can be operated on by an expert system external to the LRI/LRU (in a portable maintenance aid, for instance) to effect significant RTOK reduction. This serves to reduce the burden on the support system as well as improving system availability to the user directly.

Figure 4.3-1 shows a sample hardware data log contained in ESDR hardware installed on a line replaceable item. In this case, LRI fault logging devices are slaved to a system master processor (referred to as the OBD, or on-board diagnostic computer)when the LRI is installed into its host system. Data entry is made into the fault logging device non-volatile storage at all levels of assembly. First, the depot or manufacturer makes an entry into the fault log to provide it with serialization, part number, revision codes, etc., generally via Special Inspection test equipment used to test/diagnose the LRIs health. The LRI identification information is programmable because the LRI that hosts the ESDR hardware may be programmable, and the part number/revision code may be dependent on software load. Accumulated run time is stored into each LRI fault log as part of the system shutdown sequence, by the system OBD processor. The last entry made into the LRI identification block is a pointer into Non-Volatile Memory (NVM), identifying where the maintenance record blocks are to be found. Each Maintenance record block in the NVM, then, contains a pointer identifying where the last fault log block related to it can be found. The maintenance data block also contains information relating to the installation of the host LRI into the system. This information can be used to diagnose faults that are installation related (i.e., faulty connectors on the rack, faulty cooling, etc.). In this example, fault logs can be instantiated by a number of different avenues. First, the system OBD processor will insert a fault log into any LRIs that are suspect in a particular system performance failure. Second, the system OBD processor will insert a fault log into an LRI whenever an out of tolerance environmental condition exists in that LRI. For instance, the OBD processor would update the fault log of all LRIs in the system if it determined that an acceleration or vibration overstress had occurred, whereas only a specific LRI fault log would be updated if that LRI had overtemped due to low coolant flow through it. Third, the operator (pilot) could update all of the LRI fault logs (it would overtax the operator to have to select specific fault logs to update), by switch action, if he felt that there was anomalous system behavior, either environmentally related, or not. The fault log is time tagged to allow the information to be related to system telemetry gathered by some other means, by correlating the telemetry to the switch action that instantiated the fault log.

One advantage of including ESDR into the organizational maintenance concept is that the maintenance log is carried along with the LRI to every maintenance level. If, then, an LRI is removed at the organizational level, due to a failure that is induced by the environmental conditions that the system is being subjected to at the time of the failure, and returned to a repair facility, the repair facility is afforded the advantage of the knowledge of what that environment was. That information could then be utilized to stimulate the LRI to failure by replicating the environment in some manner after the UUT RTOKs without the stimulus applied. This, then, ensures higher quality stock being returned to the stockpile. Another benefit of incorporating ESDR at this level of assembly and making it interactive with the on board diagnostic capability is a reduction in the number of LRIs that are returned to the repair facility only to RTOK. This is because the maintenance processor in the system, upon determining that a failure has occurred that involves more than one LRI (ambiguity) can annotate each LRI as having a 'possible failure'. An off board expert system could then be brought to bear to determine, based on each LRIs failure history, which is the best candidate for removal. For instance, if three LRIs are suspect in a specific system failure, the PMA (Portable Maintenance Aid) expert system could search each LRI's failure log and adjust its estimate of the likelihood of any LRI being the failed unit, based on a determination that any of the three had been marked as 'possibly failed' for a previous similar failure.

Word	Description	When Is Entry Made	Source
ID Block			
1-2	Part Number	Production	Assembly/Rework
3	Revision Code	Production	Assembly/Rework
4-5	Serial Number	Production	Assembly/Rework
6	Accumulated Run Time	At End Of Each Mission	BIT
7	Series Pointer	Production	Assembly/Rework
Maintenance Record Block			
1	A/C Tail Number	On R/R Action	PMA
2	Rack Locator Reference	On R/R Action	PMA
3	Slot Location W/I Rack	On R/R Action	PMA
4-5	Date Of Installation	On R/R Action	PMA
6-7	Maintainer I.D.	On R/R Action	PMA
8	Local Fault Pointer	On Fault	BIT
Fault Log Block			
1-2	Date Code	On Fault	BIT
3-4	Time Stamp	On Fault	BIT
5-8	Environmental Data	On Fault	BIT
$9\text{-}10_{16}$	BIT Data	On Fault	BIT

Table 4.1.1.3-1. LRM Fault Log Format

8/19/98
Wm. W. McAdam

The costs of adding ESDR to the lower levels of assembly are similar, but, due to the fact that the capability is distributed throughout the system rather than centralized to a single monitoring and data storage device, the costs are increased as a function of the number of LRIs that comprise the system. Also, the ESDR device imposes a burden on the maintenance concept at all levels of assembly That is, the battery power that allows ESDR to sense environments when uninstalled (when the LRI is in storage) now represents a wearout at both the organizational as well as depot level. This burden must be accounted for in both the O-level and depot level IRAN cycles.

If ESDR is incorporated into the on board diagnostic (OBD) design, one additional problem that the designer is presented with is a result of the ESDR hardware being mounted on unique hardware assemblies. That is, BIT software incorporating test vectors for the LRI on which the ESDR package is to be mounted must be unique to the assembly hosting the ESDR package. This would result in each ESDR package being a unique part number, resulting from the unique vectors residing in its non-volatile memory. One approach to dealing with this problem is to allow the ESDR processors to communicate via a digital bus (P1149.1, etc.), each slaved to a master diagnostic processor in the system The ESDR is then only equipped with a Kernel that allows it to be slaved to the OBD master and accept test vectors via the bus.

4.1 Utilization of ESDR at Lower Assembly Levels - An Example

If we were to install an ESDR package on each LRM, similar to the ESDR unit described above, what would be the benefits? The costs?

First, implementation of an expert system to operate on the maintenance history information would result in reduction of RTOKs at the test and repair facility. This would unburden not only the maintenance and repair facility, but would also result in reduced loading on transportation and handling facilities.

Second, since the maintenance history of the assemblies storage is distributed within the assemblies themselves, the cost of providing centralized support system computing data storage is reduced Additionally, since the data is distributed with the hardware, any expert system software used to operate on that data is made portable, thereby reducing demands on the support system further.

Third, using the on-assembly stored environmental data as described in the previous chapters to identify environmentally induced failures will further reduce the demands on the support system in general.

Now, what does adding the ESDR capability to a system cost? If, as was previously stated, the decision to include ESDR in a system design is based on the Life Cycle Cost impact, it should be readily seen that the trade is between system acquisition cost and the savings in support system acquisition cost. If now year and then year cost adjustments are made. Then the trade generally becomes one of acquisition cost for the system (due, primarily, to the cost of the ESDR hardware itself) vs. acquisition cost for the support system (i.e., computing power, trucks, test equipment ,etc.).

5.0 Making use of ESDR Environmental Data

The primary use of ESDR environmental data is to determine the accrued damage that has been incurred by the item in storage/use throughout its life. For the purposes of this discussion, we will assume that the ESDR data recording capability is carried on the lowest replaceable unit at the organizational level (such as would be the case if ESDR were associated with a 'wooden round' missile.

Application of ESDR data and hardware life modeling requires that the hardware be characterized for its reaction to the various environmental stimuli that are expected to be encountered in the system design life. This is best done in the design phase, and is generally an output of mechanical design of the system. Modeling done in the mechanical design will give the designers (and, later, the maintenance manager) a tool to predict how the hardware reacts to temperature and vibration. This information can be confirmed in any accelerated life testing done as part of qualification testing of the system, and then applied to the life model of the system. In our example, we will assume that humidity can contribute to degradation in the system life characteristics. However, since our ESDR design for the support system includes appropriate humidity sensing and alarm capability (and, hence, any occurrence of out of tolerance humidity in storage will be corrected promptly), the wearout model for the system will include only effects of temperature and vibration/shock.

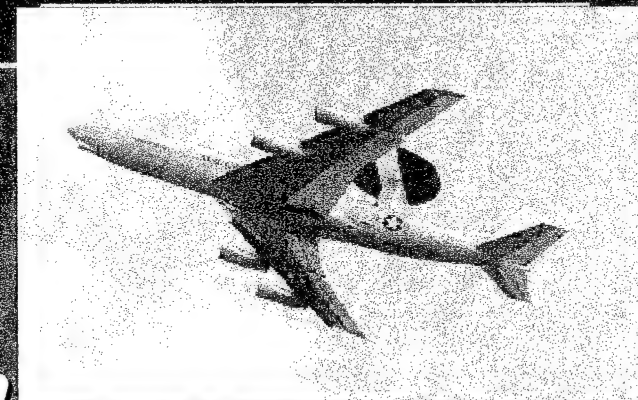
The dynamic model for most systems is not predicated on the effects of the system transitioning through a range of temperatures and not the specific minimums and maximums of those temperature swings. One approach to obtaining pertinent environmental data and minimize ESDR processor activity has been to equip the ESDR hardware with sample and hold circuitry that is always enabled and which senses the 'turnaround' temperatures of a temperature swing (the point at which a rising temp swing turns to a lowering swing (or a maximum), or visa versa). At the transition time, an interrupt is generated to 'wake up' the ESDR processor which then determines the temperature range by subtracting the minimum previously identified from the maximum most recently measured at the turnaround. The processor then increments a counter in the appropriate 'bin'. When the maintenance manager then queries the ESDR data log, he then has at his disposal a pictogram of how many excursions the hardware has seen of each temperature range. Each 'bin' is associated with a different life acceleration factor as relating to the initial dynamic model, thereby identifying how much 'life' has been lost, due to the quantity and range of thermal excursions experienced by the hardware.
In a similar manner, a threshold level is determined, below which high cycle fatigue (vibrational or shock stresses) are considered to have 'little or no effect'. The accelerometer package associated with the ESDR hardware is then equipped with a thresholding circuit used to 'wake up' the ESDR processor if the threshold is exceeded. The ESDR processor will then perform appropriate processing on the raw accelerometer data to identify which frequencies of vibration are above the threshold level and by how much. The processor then 'bins' the data in a manner similar to temperature data discussed above, except that the bins are a function of frequency content and G level. Additionally, the processor must determine the amount of time that the environment was encountered, and increment the record for that frequency and G level with the duration of the excursion.

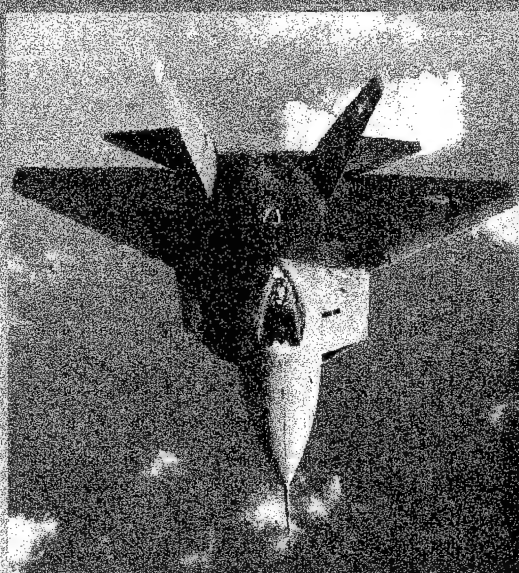
5.0 ESDR and warranty

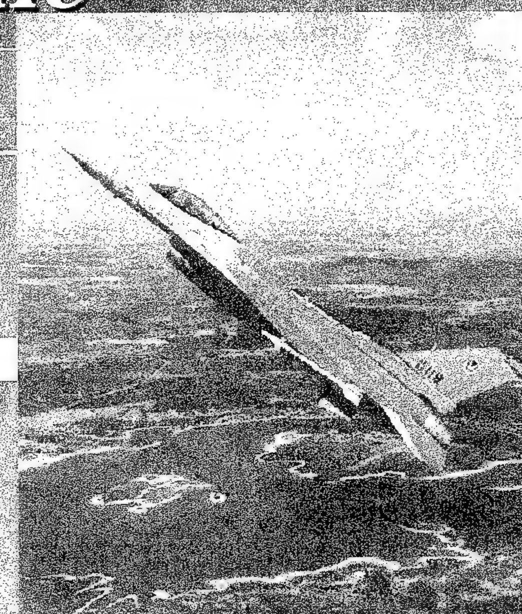
The inclusion of ESDR into the stockpile management process provides some interesting possibilities in the development and administration of system warranties, all of which should result in lower warranty cost at acquisition time.
First, incorporation of ESDR into the system support concept allows the contractor to consider a 'mileage' clause in the warranty contract. This means that the contractor no longer would bear sole risk that the system will be used in the 'ideal' manner described in the system specification. Currently, the contractor must cost the warranty assuming that a high percentage of systems warranted will be used in accordance with the environmental specifications, but that some number of units will be used for training, evaluation or other non-tactical functions, and, hence, will experience 'accelerated' wearout. The contractor cannot design in additional durability to accommodate these non-representative usage scenarios without adding significantly to acquisition cost, and is left with upscaling the cost of the warranty, or adding specific, sometimes extreme, exclusion clauses to the warranty contract. By allowing the assessment of wearout incurred in these non-ideal environments and adding appropriate wording to the warranty contract, the warranty can be tailored appropriately.

The benefits of utilizing ESDR in relation to warranty administration are not uniquely with the user, however. The contractor in afforded the ability to void the warranty on a specific system if it is significantly mishandled (dropped by a maintainer, etc.), or misused, such as would be the case if a specific system was used in training scenarios when the projected usage environment for the 'fleet' showed limited deployed use. An example of this would be missiles, which are, essentially, 'one shot' devices. In this case, a warranty would have to be negotiated that designated some number of missiles as 'for training use' and either excluded them from warranty applicability, or made special provisions for warranty costing of those items. Again, the dynamic model of the hardware, and projected usage profiles for the training aircraft would be employed to determine the 'rate of wearout' and provide the contractor with a basis for cost estimation.

Environmental Sensing As An Input To Stockpile Reliability Management







JAWSS Symposium

Briefing Elements

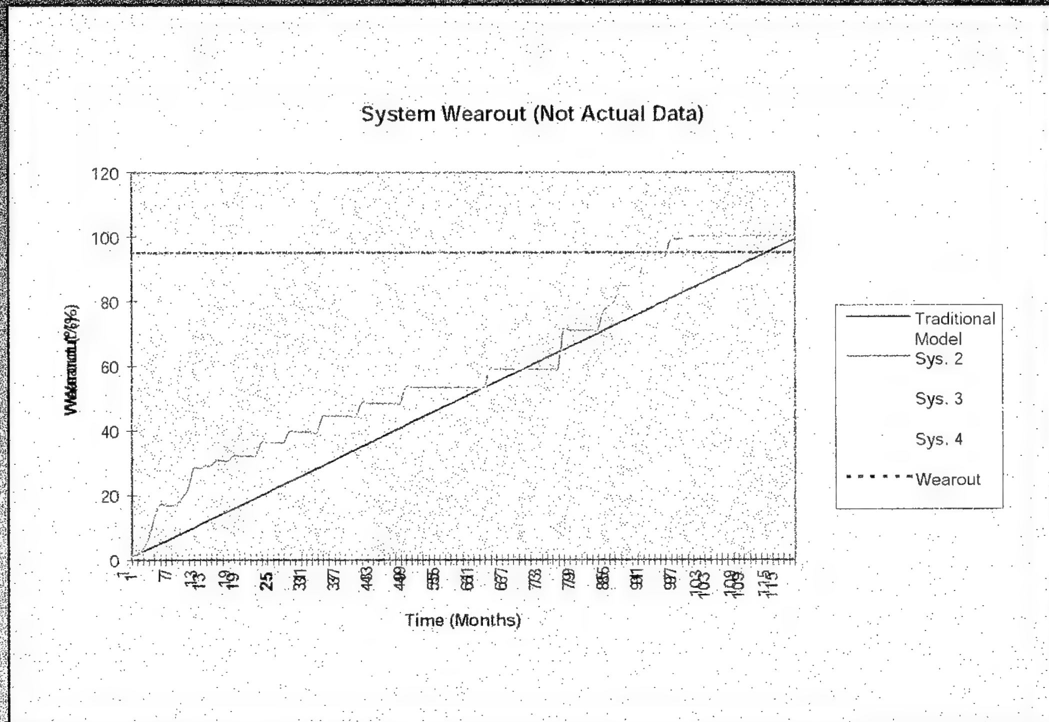
- Support Concepts and Life Modeling
- ESDR Used To Enhance Overall System Supportability
- Systems Applications
- ESDR And Warranty

Relationship Between Environment & Wearout

- Traditional Support Concepts Assume Linear Relationship Between Age and Wearout

- Wearout Is a Function Of Usage Environment Relating To Accrued Stress/Strain Damage

- Environments, Applied In Differing Sequence Cause Wearout Of System At Different System Ages



Adding ESDR To Support Concept

- Aids Identification of RTOK (Retest OK) Hardware
  - Account For As Much As 25% of Maintenance Actions In Some Systems
- Reduces Environmentally Induced Intermittents
  - Subset Of RTOKs, But With Unique Approach To Corrective Action
- Aids In Shelf/Service Life Extension Planning
- Can Reduce Warranty Cost

ESDR Aids All Levels Of Repair

Organizational Level

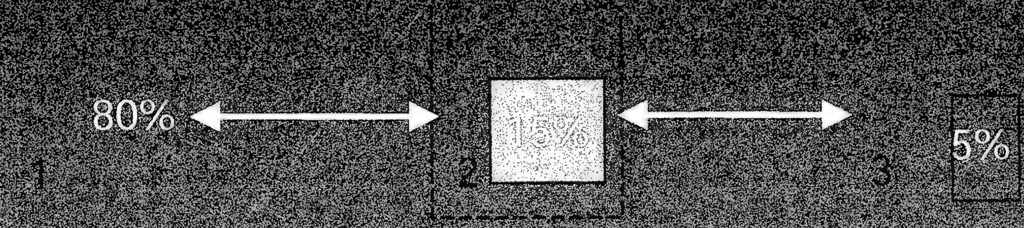
- Communicates Via T/M Bus (Provides Redundant Stimulus & Response Path For Test)
- Aids In Breaking Ambiguity Groups By Facilitating Expert System Application
- Identifies Environmentally Induced Intermittent Failures

Depot Level

- Environmental Histogram Aids In Prognostics
- Identifies Items That Have RTOK'd Before In Other Systems
- Identifies Environmentally Induced Intermittent Failures
- Aids in Life Extension Planning

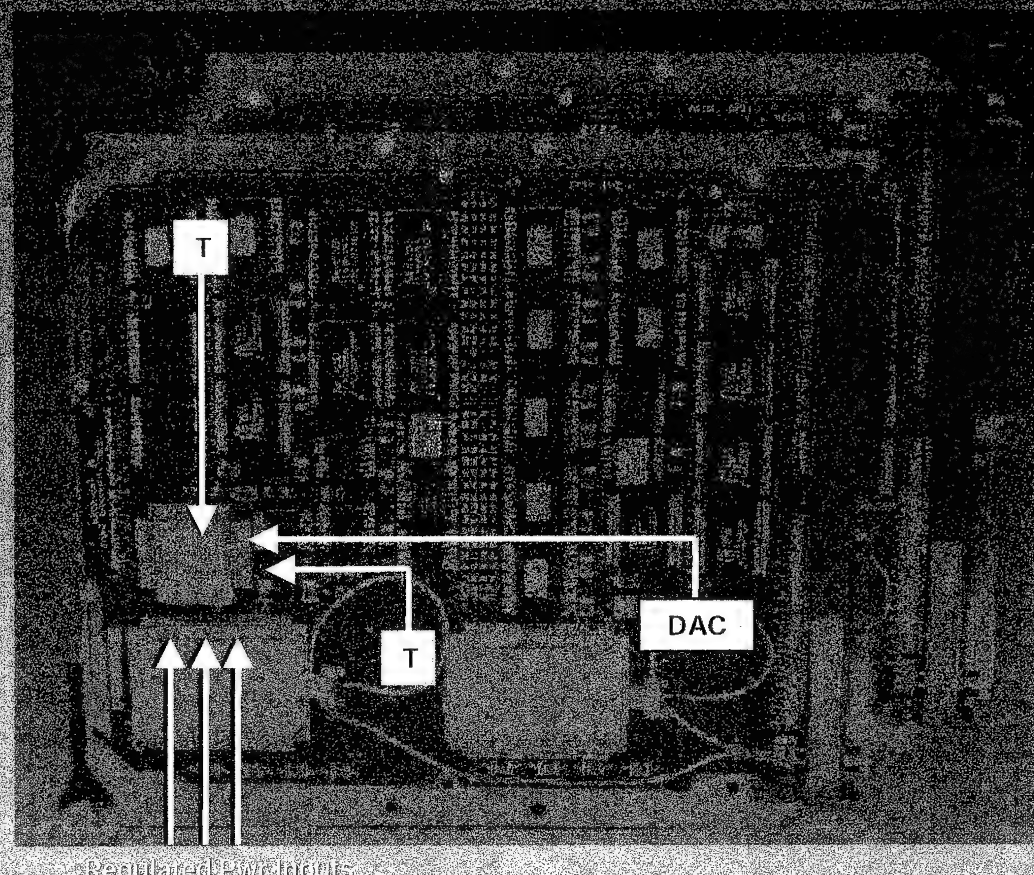
ESDR Aids In Breaking Ambiguity Groups

If Function 'X' Is Distributed Across LRIs As Illustrated



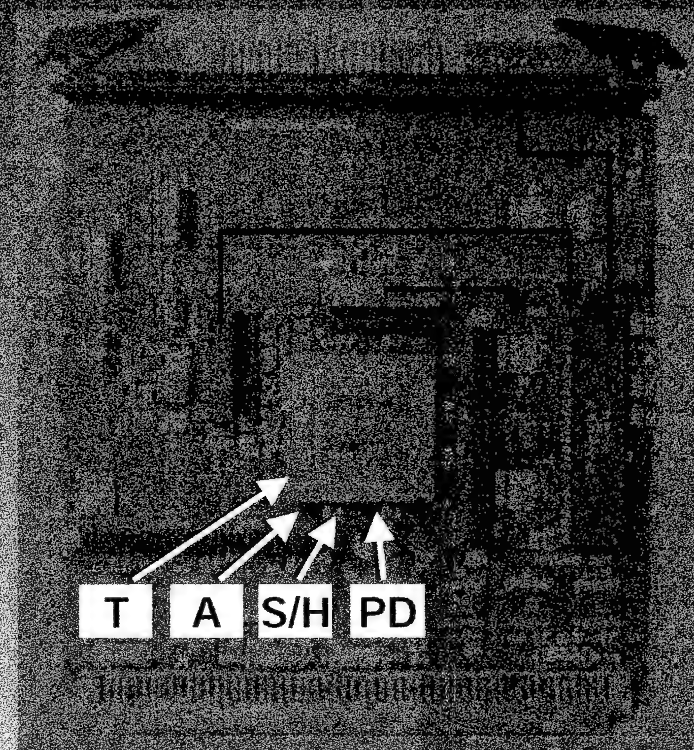
ESDR Equipment Application

- Single Chip Computer
  - Multi Sensor Input
  - Analog And Digital Test Inputs

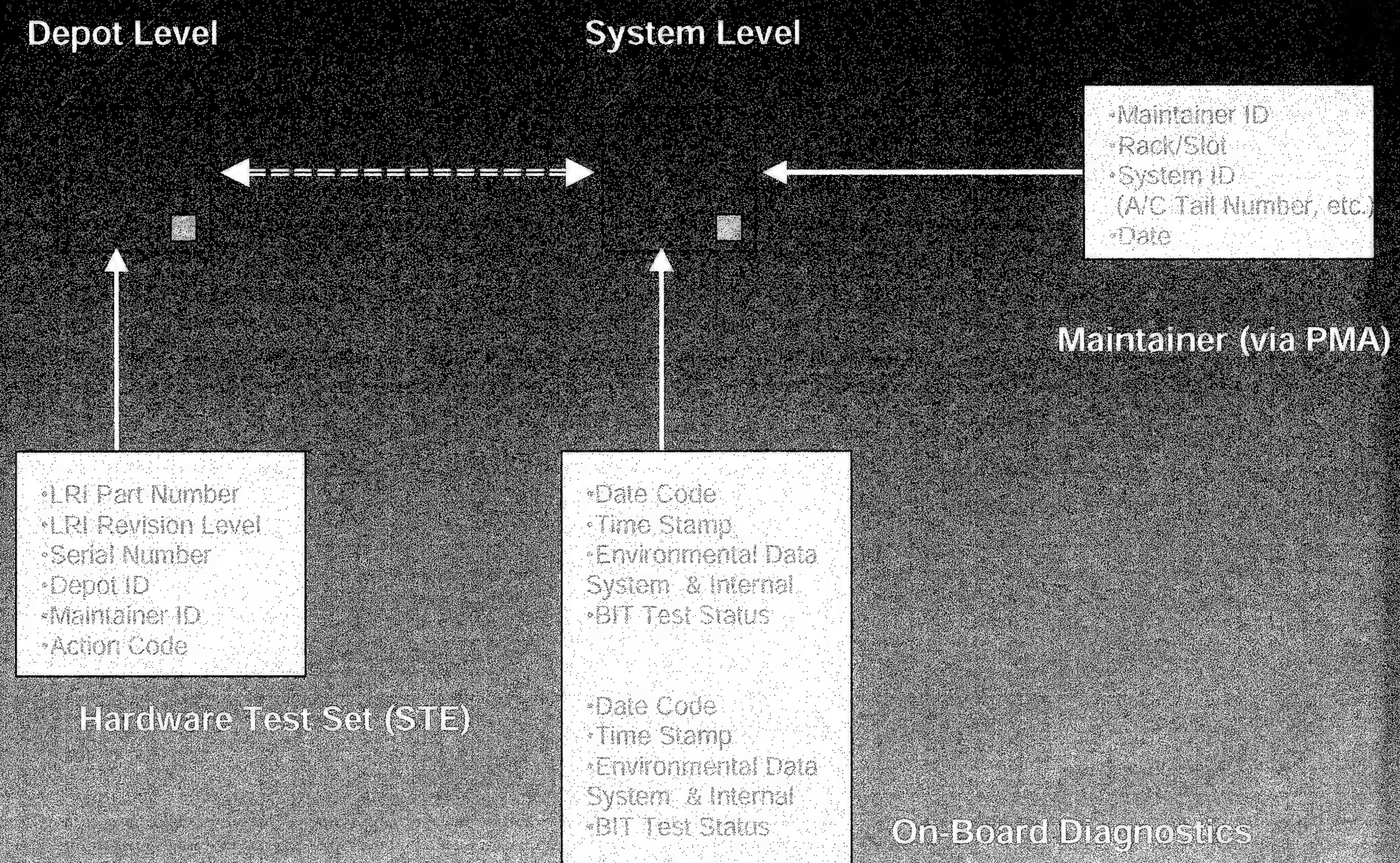


Fault Logging

- EEPROM Must Be Sized To Accommodate 'Lifetime' Of Data
- Sometimes, Memory Size Determines Logging Mechanization
- Environmental Monitoring Overstress vs. Periodicity



Fault/Environmental Data Log



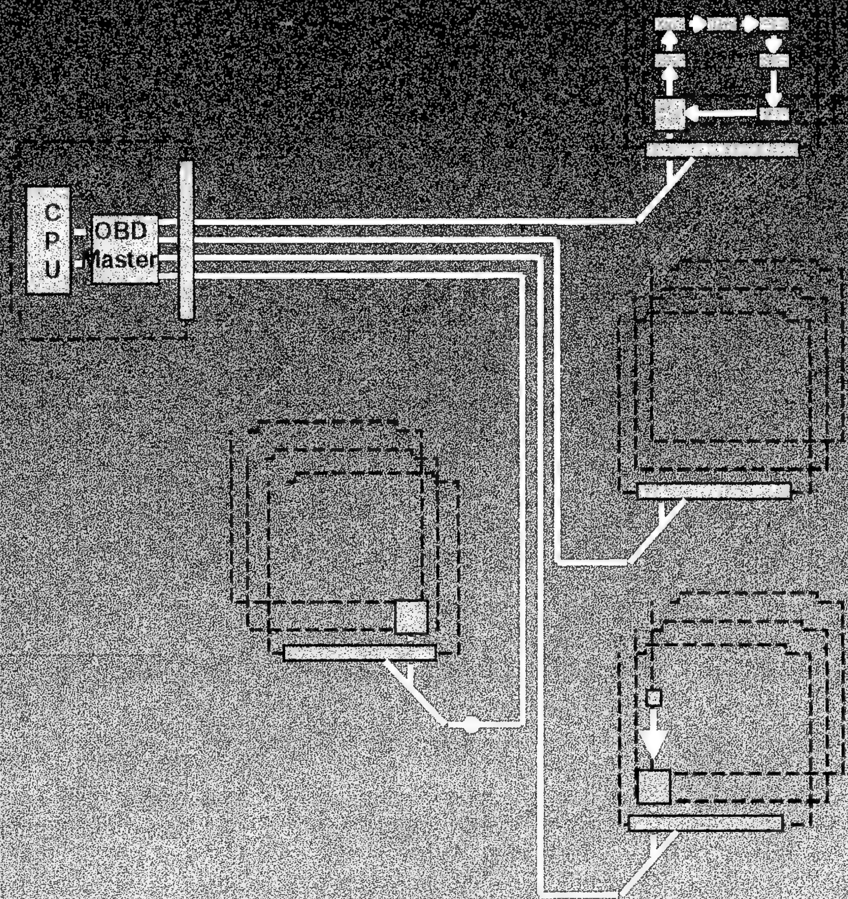
ESDR Stress Summary Fault Log

- ESDR Determines and Records 'Turn-Around' Temperatures
- Fault Log Is Updated At Each Excursion 'Turn Around'

Thermal Cycling Summary

Range Of Thermal Cycle	Number Of Cycles Incurred
15oC	2
20oC	15
25oC	0
30oC	25
35oC	8
*	*
*	*
*	*
*	*
100oC	25

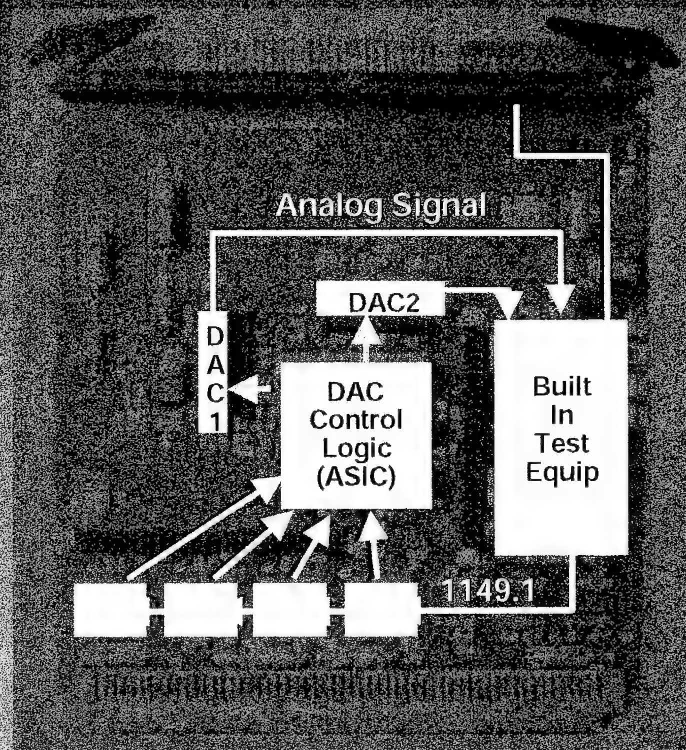
ESDR As An Element Of Diagnostic Architecture



- IEEE -1149.1 Boundary Scan Test Control
  - Component Level FD/FI
- Digital Test Input
- Regulated Power Supply Current/Volts Monitor
- Subsystem Level Control
- Environmental Sensing
- System Timing Monitor

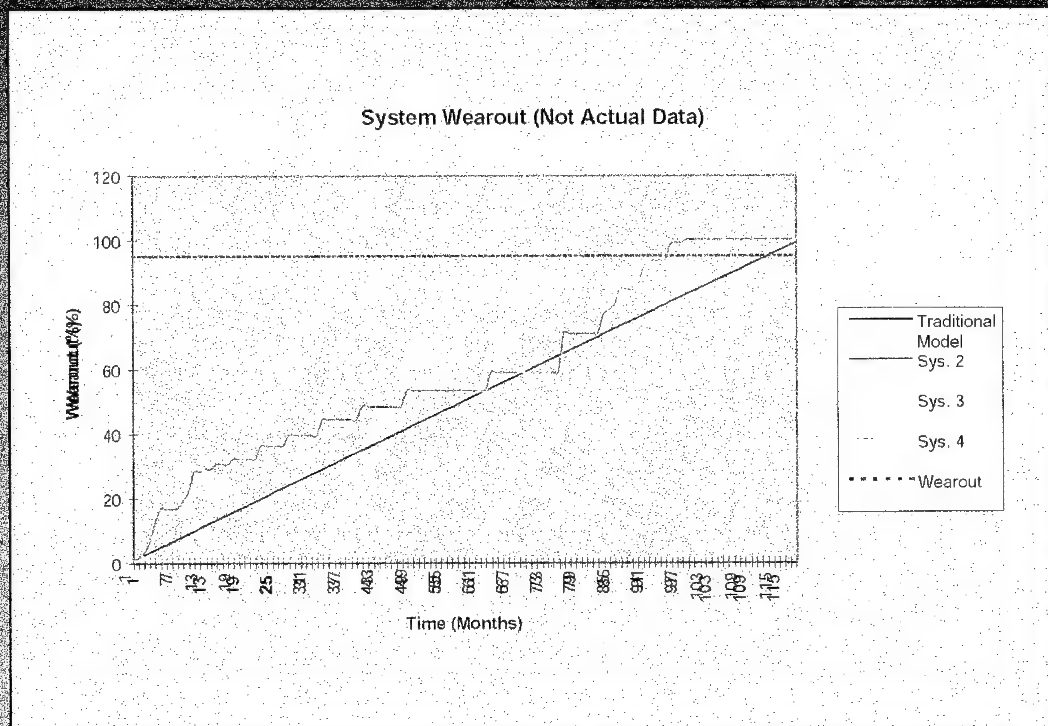
Advanced Built in Test Equipment

- Autonomous Self Test at the SRU level
- 1149.1 Boundary Scan Control of DACs
- Environmental Monitoring



Warranty Administration With ESDR

- Now have a 'Mileage' Measure, As Well As Time
- No Longer Have To Base Warranty Cost On Some Number Of Systems Being Used In A Manner Other Than Planned
  - Used Up More Quickly



UTILIZING SIMULATIONS FOR PERFORMING DEGRADATION TREND ANALYSES

Eric E Hunt, CRE
Product Assurance Directorate
U.S. Army Aviation and Missile Command
Redstone Arsenal, AL

ABSTRACT

The process of modifying a simulations model for supporting stockpile reliability program (SRP) analyses of a tactical missile system is described. Basic application of the modified simulation to SRP analyses is discussed. A methodology for supporting degradation trend analyses by predicting future performance is developed. Examples from an ongoing analysis are provided. It is shown that this is a valuable tool with significant growth potential. Model programming and system design considerations that should be incorporated early in program development in order to optimize future applications of the methodology are discussed.

INTRODUCTION

Missile systems are originally procured with a predicted shelf life. After fielding, system data is analyzed to assess the original shelf life prediction and perform shelf life extensions whenever possible and necessary. This Army program is referred to as the Stockpile Reliability Program (SRP). Historically, Army missile systems have been procured with an average seven-year shelf life, however, through the SRP the shelf life has been extended to an average of 18 years. SRP utilizes a variety of test methodologies and analysis techniques customized to each missile system. In general, data is collected over the life of the missile system from surveillance (field storage and operations), flight testing, and disassembly/component testing. This data is then analyzed for trends associated with age, manufacturing strata, and exposure environments. Undesirable trends may result in suspension, restriction, or risk acceptance. When the system continues to perform reliably and safely, and still meets a tactical need (i.e., is not obsolete, or replaced by a new system), then a shelf life extension will be coordinated with the Army missile community. For obvious reasons this program attains high visibility. For example, extending a system's shelf life may have a significant impact on the decision to procure a replacement system. Shelf life extensions must be taken seriously, with the greatest possible statistical confidence imposed. Unfortunately, due to significant operating budget shortfalls, the Army SRP is extremely constrained. Accordingly, several new initiatives have been undertaken in SRP to improve the confidence of the analyses at equivalent or reduced costs. One of these initiatives is to extend the use of simulation models created during system development for assessing and predicting missile system shelf life.

Specifically, this paper reflects efforts associated to the HELLFIRE SRP. The HELLFIRE SRP utilizes an annual sample of 15 HELLFIRE missiles for disassembly and component testing, and 21 missiles biennially for flight testing. In general, all of the samples are selected from dedicated assets. These are missiles that were sampled across production and set aside specifically for SRP testing. HELLFIRE model AGM-114A (PA79) and AGM-114C (PD68) missiles were sampled, starting in 1985, with a total of 487 dedicated assets assembled by 1989. These missiles were electronically all-up-round (AUR) tested and then placed in carport type structures in Alaska, Arizona, and Panama. These structures expose the missiles to the environment while not subjecting them to direct precipitation or solar loading. The missiles are maintained in their original shipping containers IAW the HELLFIRE Supply Bulletin (SB) 742-1425-92-010. The Army HELLFIRE SRP was designed to promote natural accelerated aging (within the specified storage limits) in order to project future stockpile performance by identifying trends in the dedicated assets prior to their occurrence in the stockpile. In addition, samples may be selected from the field for special tests. For example, a total of 48 missiles were sampled from the Operation Desert Storm retrograde. Twenty of these missiles have been flight tested, and 14 of these were disassembled and component tested.

After performing HELLFIRE SRP sample selection, the missiles are shipped to the Redstone Technical Test Center (RTTC), Redstone Arsenal, Alabama. The RTTC provides AUR testing, X-ray, disassembly, and component functional testing. Propellant samples are provided for chemical and mechanical analyses. Missiles selected for flight testing are provided to Eglin Air Force Base after the completion of AUR testing and X-ray at RTTC.

A total of 206 SRP missiles have been tested since 1990, with 120 missiles being component tested and 86 being flight tested. It should be noted that there are additional sources of data that are monitored for trends, e.g., malfunction reports, ammunition condition reports, quality deficiency reports, etc. Additionally, surveillance vans perform non-destructive electronic testing of the dedicated assets and other samples from the inventory annually. The surveillance van measures 126 electronic parameters, and is the source of over 20,000 missile tests.

Until 1993 there was no capability to analyze the extensive amount of data that had been collected on the electronic components. These components have numerous performance parameters that can be tested at several environmental conditions without destroying the component, thereby producing a large amount of data. A high priority was placed on loading this data into a system that could be accessed, downloaded, and then analyzed using a desktop personal computer. This effort was completed in December 1993 and currently contains over three gigabits of SRP and surveillance data.

Generally, SRP analysis involves plotting parameter data versus age at the time of test, then performing curve fitting to identify parameters that display statistically significant trends. An example of this type of analysis is shown in figure 1. When a trend is identified, the reliability engineer is confronted with the task of determining what affect (if any) the trend will have on the missile system's reliability, safety or performance. This is often not an exact

science. Parameter specifications were often the result of engineering judgment to begin with, and the actual point of mission affecting failure could be at the specification limit, or far outside it. Additionally, the combined affect of multiple minor trends, for which the individual parameters approach the limits but do not exceed them, cannot be evaluated through this traditional trend analyses technique.

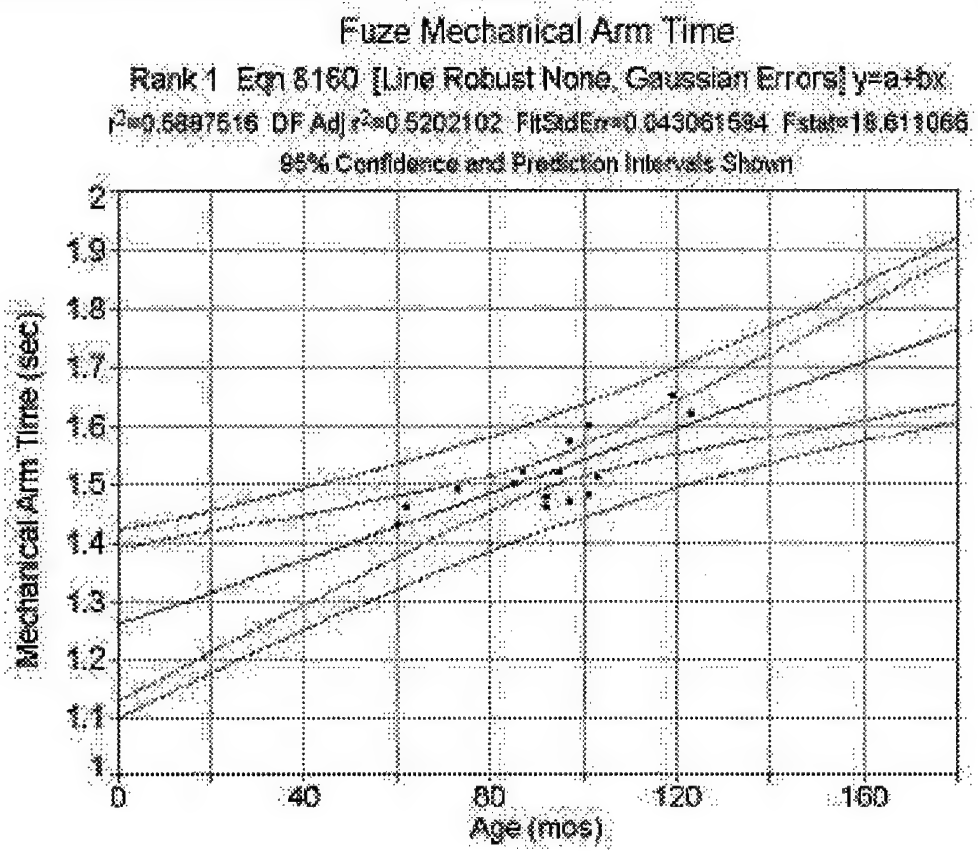


Figure 1. Example of traditional SRP trend analysis. (Note: Data not to be construed as actual)

MODIFICATION OF THE SIMULATIONS MODEL

A six-degree-of-freedom (6-DOF) simulations model known as the Laser Designator Weapon System Simulation (LDWSS) was originally developed to support development and production of the HELLFIRE missile. The LDWSS runs a multiple number of trials per scenario in a Monte Carlo fashion. It can output various plots such as trajectory and miss distance. The system calculates circular error probability and probability of hit.

After the electronic component SRP data was successfully transferred to database we identified the need to find a better method for analyzing the large amount of data. We also

became aware of it's significant potential for simulations applications. Based on consensual identification of this need, several agencies teamed to modify and validate the original LDWSS model for this application. The approach was to initially bring the simulations personnel together with the test personnel. The test personnel provided background information to the simulations personnel on all testing and parameter readings taken during SRP tests. With this information, the simulations personnel were able to identify which of the parameters could be applied directly to the existing LDWSS model, and which could be applied through minor modifications to the model. Then, in a team effort between system engineers, SRP analysts (reliability engineers), and simulations personnel, optimum areas for modification of the LDWSS model were selected. For example, if a modification could be made to allow entry of a specific parameter, but it was identified by the system engineer that the parameter would have insignificant impact on system performance, or it was determined by the SRP analyst that the parameter would be unlikely to change with age, that modification might not be performed in lieu of other more critical. Modifications were performed in the seeker, control section and autopilot models. Additionally, a simple model, which did not exist previously, was developed for the thermal battery and integrated with LDWSS.

In the process of this development, it was realized that the original means and distributions for the parameters used in the LDWSS were not necessarily reflective of the readings actually being measured in SRP testing of the inventory. This should not have been a surprise, since the means and distributions were based on the specification requirements, combined with engineering analyses of what distribution would be expected for each parameter. No known "follow-on" attempt to analyze data on actual production hardware in order to re-calculate means and distributions had ever been performed. Using the SRP database the simulations personnel developed more realistic means and distributions for all available parameters based on actual data collected on 0-4 year old missiles. This became a significant, yet initially unplanned modification to the simulations model. After reviewing the planned modifications with all members of the development team, the simulations personnel performed a validation-verification utilizing available flight test data. Effort was then shifted to the application of the model.

BASIC APPLICATION METHODOLOGY

When the exemplary work to modify the model was completed, the reliability engineer became involved in determining how the simulation would be applied. It was quickly apparent that the other personnel on the team had their own ideas of how to apply the model, and at that time, we had insufficient funding to further influence the effort. Emphasis was therefore placed on performing applications of interest to the systems engineers. These analyses would be the most likely to have an immediate impact on the ongoing production of follow-on models of the HELLFIRE missile.

Component testing of SRP assets has often identified failures of items for specific test parameters. The systems engineers believed that most of these "failures" would have little or no impact on system performance. In general, this became the basis for utilizing the simulation to "re-build" a missile from it's component test results. For example, even if a missile failed to meet a specification parameter, how would it have performed if actually flown? Therefore, the direction by the systems engineers was to "re-assemble" missiles from their component data, and "fly them" in the simulation. The next step was to identify appropriate flight test scenarios. Working with test engineering and a seeker technical expert, 20 flight scenarios that were believed to represent "edge of the envelope" performance were selected. These vary in range, offset angle, flight mode, and designation delay. For two years, all of the component data for each SRP missile sampled (15/yr, 30 total) was plugged in to the model to simulate how the missile would have performed if it had been flown at each of the 20 scenarios. It was decided through limited engineering analysis that 5000 run-sets for each scenario would be used. This was considered a large enough sample to support statistic statements. "Rebuilding missiles" in the simulation was not without merit. For example, one control section failure that previously was believed would not affect system flight, was identified to affect probability of hit under specific scenarios. Under previous methodologies, we would have concluded that this missile would not have been affected by the minor failure. Using the simulation, it was discovered that the missile would have had significant reductions in the probability of hit under some flight scenarios. Discovering this, even on only one of 30 missiles analyzed, was a significant advance in SRP analysis.

Recall the original objective of the SRP program, "to predict the future performance of missile systems". It is apparent that this re-building of missiles in the simulation has limited value for satisfying this need. However, we could now report something to the effect that "if these 15 missiles, ranging in age from x to y years were flown in this scenario, z% would have hit the target." This was an improvement. We could "fly" an SRP missile over-and-over under numerous scenarios after it had been re-created in the simulation, but it is clear that there is room for additional application methodologies.

DEGRADATION TREND ANALYSIS METHODOLOGY

Generally, most persons involved in the project only identified with the capability to calculate probability of hit for missiles of various ages. They felt that trend analyses could then be performed on the relationship between probability of hit versus age. Unfortunately this provides no significant improvement to SRP analyses. Based on the missiles being spread across various ages, combined with the fact that missiles could not be re-built in the simulation if one component experienced a hard failure, this methodology yielded a very small, loosely distributed sample set. An example of this methodology being applied is demonstrated in figure 2. These analyses exhibited very low statistical confidence. Additionally, it took no advantage of the extensive amount of test data collected on the inventory utilizing the surveillance van.

As stated previously, there are two significant shortfalls with the traditional method of SRP analysis based on individual parameter degradation trends. One is that it is often difficult to determine the point at which a trend will affect the missile mission. The other is that it is impossible to evaluate when a combination of minor trends will affect the missile mission. We needed to develop a new

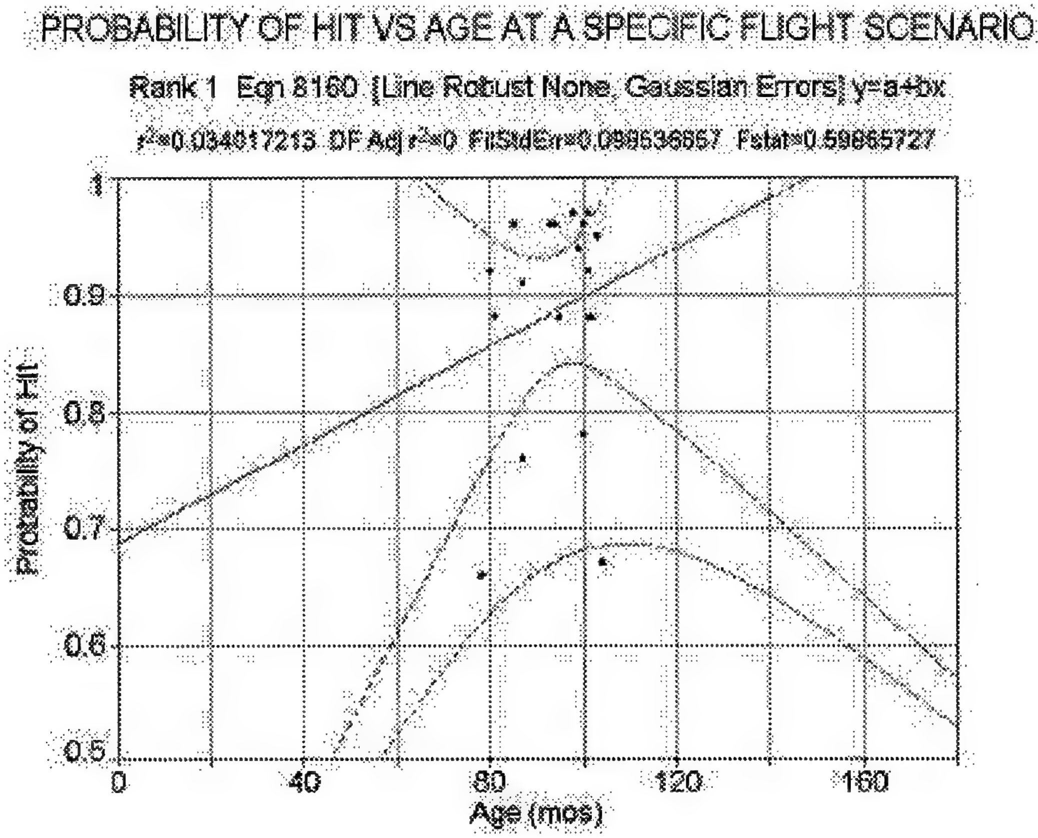
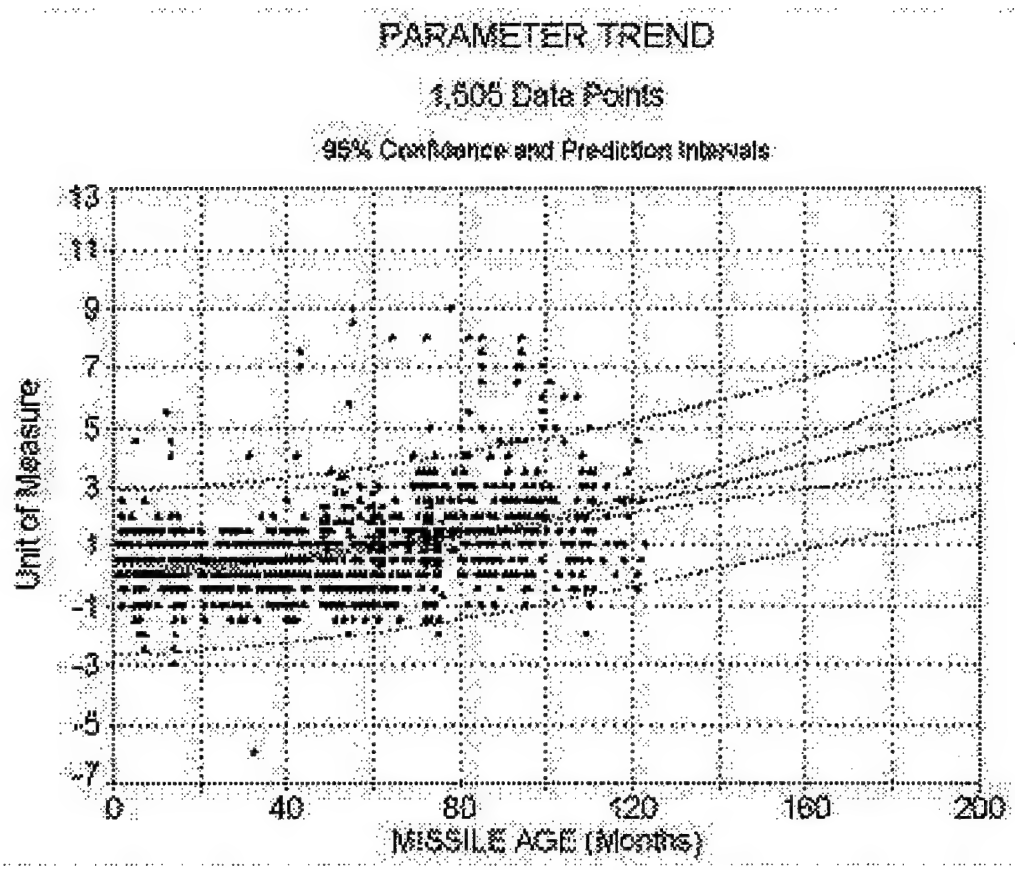


Figure 2. Example of probability of hit based trend analysis. (Note: Data not to be construed as actual)

approach for application of the simulation. The new methodology identified is simply an extension of the current trend analysis process into simulations. This method optimizes the available SRP data, and eliminates the shortfalls of the traditional method. Utilizing the HELLFIRE SRP database, thousands of readings taken on many of the electronic parameters is plotted versus age for trend analysis. The large number of readings provide trend analyses of high confidence. Figure 3 provides an example of one of these trend analyses for three to ten year old missiles. The fitted line is projected out as a prediction of the performance of this parameter in the future. This analysis is performed on hundreds of individual parameters. Other than being able to now utilize the significant amount of data being entered into the SRP database, this is the same as the traditional method of SRP analysis. The next step is the new approach. Using figure

3 as an example, we extract a predicted mean and distribution for this parameter at 15 years. This same "extraction" can be performed from all of



the individual parameters trend analyses. The extracted parameter means and distributions are simultaneously input to the simulation, "building-up" the predicted model for a 15 year-old missile. This model can be run through 5000 run-sets for each of the standard 20 flight scenarios. This effort utilizes all available test data, identifies actual missile performance impacts of all parameter trends combined, and predicts future performance.

LIMITATIONS OF PERFORMANCE PREDICTION

Utilizing this new method does not eliminate limitations associated to the traditional process of performing degradation trend analyses of individual parameters. That is, the mathematics of plotting the data and applying a best-fit line for predictions is the same. This process is subject to difficulties in determining that trends are actual age degradation, and not associated to some change in test methodology, sample population, etc. Additionally, this

process does not identify the mechanism behind the trend, which should be determined in order to validate the prediction.

There are also some parameters for which trends or failures cannot be analyzed well using the HELLFIRE simulation. Generally this includes all of the "one-shot" components (thermal battery, gyroscopes, accumulator/ regulator, rocket motor, warhead, and S&A). Some of these devices have no/limited modeling fidelity in the simulation. For example, in the case of the thermal batteries, there was no modeling in the original simulation. A voltage level at which the missile fails hard was identified in laboratory testing. The improvement to the model was basically to create a "truncation" point for a simulated flight when the battery falls below that minimum level. This is a crude model since the power requirements and usage can be affected significantly by a variety of factors. Some of the one-shot components are treated in the simulation as go/no-go. For example, either the fuze arms or it doesn't. All of these one-shot items still require traditional SRP analyses.

There is not a developed methodology for the determination of distributions to be applied to the predicted values. Look at the point where the 15-year predicted value was extracted from the fitted line in figure 3. We could utilize the prediction lines at that age to determine standard deviation for a normal distribution around that predicted mean point. Although the use of prediction lines beyond the data set is mathematically inappropriate, the expanding lines do represent some level of increasing uncertainty in the prediction. Another method is to utilize the current distribution determined for each parameter and apply that distribution around the extracted value. Neither of these methods is considered to be the best solution and there is room for further development in this area.

CONSIDERATIONS FOR PROGRAMMING AND SYSTEM DESIGN

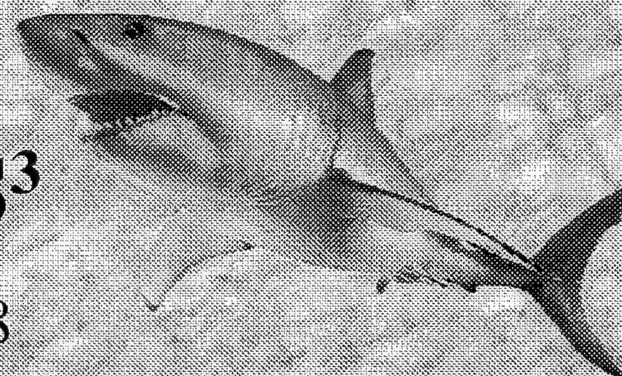
One result of the activities described herein is increased knowledge of how the simulations model should be designed for life cycle use. The fidelity of the model is critical. Subsystems should be modeled to their subcomponents, and the subcomponents to each independent output. This is obviously difficult early in the design, and requires close integration of the simulations and engineering activities. Continuous changes to the model will occur as the design is solidified. Additionally, the simulation should be revisited after full rate production to verify that means and distributions are representative of actual hardware being produced.

Alternatively, specific considerations should be taken into account for the design of the hardware. The methodology becomes more powerful if a greater number of performance affecting parameters can be non-destructively measured and input to the simulation model. Thus, the hardware should be designed for testability. The extensive use of missile hardware-in-the-loop (HWIL) testing in modern systems has indirectly resulted in significant contributions to this objective. HWIL testability requires access to critical data streams, and high fidelity simulation models.

SUMMARY

Depending on the fidelity of the original simulations model, the process described herein can be utilized to effectively develop the model for life cycle uses. However, the best case would be to plan for, and develop the model for this application early in program development. Proper development of the model for this use requires the teamwork of personnel from a variety of disciplines, to include simulations, reliability, systems, and test. Combining traditional SRP trend analysis with simulations provides a new capability to predict future performance, and has significant potential for growth into other life cycle applications.

Utilizing Simulations for Performing Degradation Trend Analyses



Presentation for JAWS S^3

16 June, 1998

Las Vegas, NV

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

OUTLINE

I. Background

II. Modification of the Simulation Model

III. Application to Stockpile Reliability

IV. Degradation Trend Application

V. Limitations & Considerations

VI. Summary

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

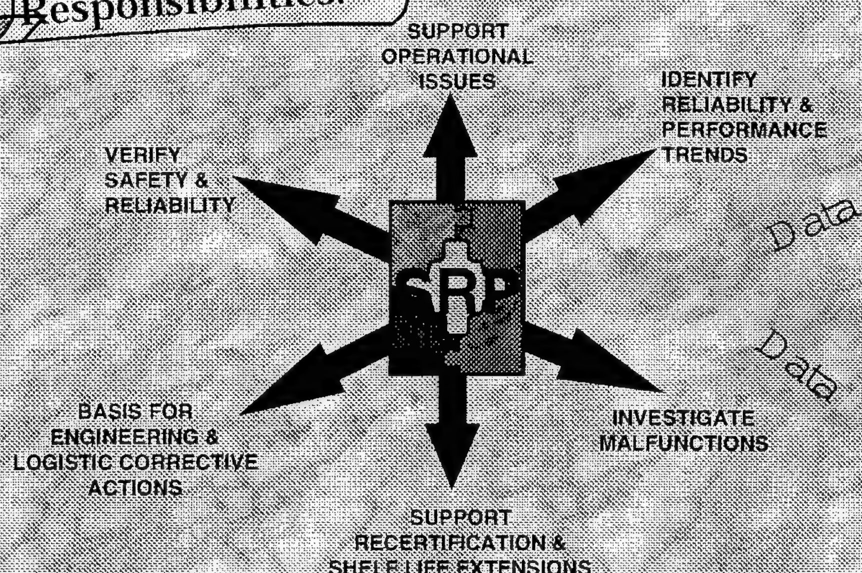
Utilizing Simulations for Performing Degradation Trend Analyses

BACKGROUND

Degradation trend activities specifically associated to the Army HELLFIRE missile system Stockpile Reliability Program (SRP).

Army Regulation 702-6

SRP Responsibilities:



Program Elements:

- Ammunition Surveillance
  - Surveillance Vans
  - QASAS
  - FSRs
- Flight Testing
  - Eglin Air Force Base
  - Missile Firing Data Reports
- Component Testing
  - Missile Inspection, X-Ray, Disassembly
  - One-Shot Component Functional Testing - Gyros, Batteries, Rocket Motors, S&As,etc.
  - Propellant Analysis
  - Lower-level Electronic Testing

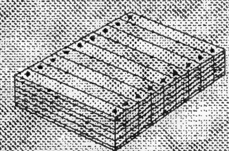
16 June, 1997

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

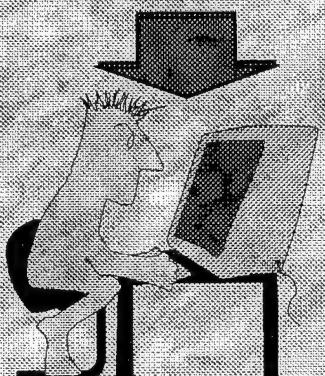
Utilizing Simulations for Performing Degradation Trend Analyses

BACKGROUND

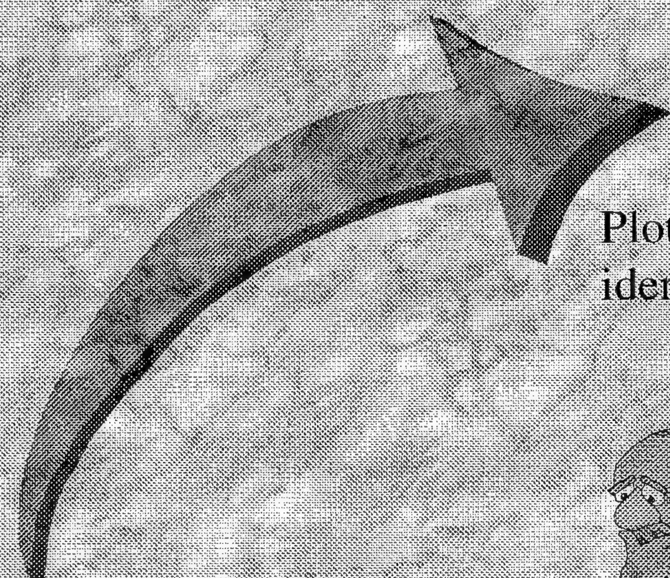
Traditional SRP Trend Analysis:

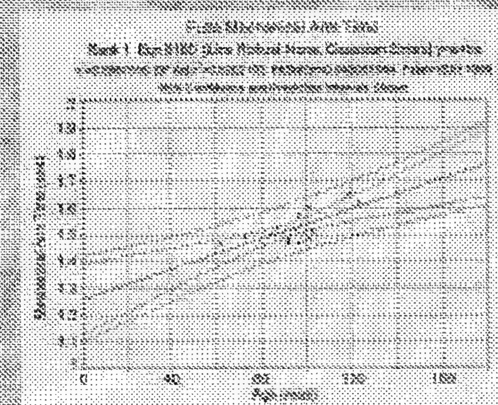


Test Data

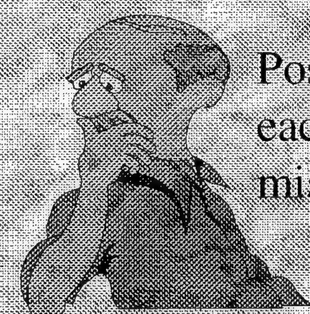


Filter the data for each parameter for validity, homogeneity, and environment.





Plot the filtered data versus age to identify trends for each parameter.



Postulate how/whether each trend will affect missile performance.

16 June, 1997

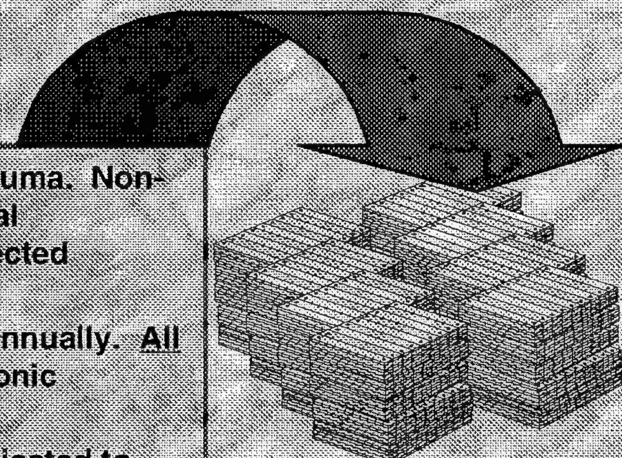
ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

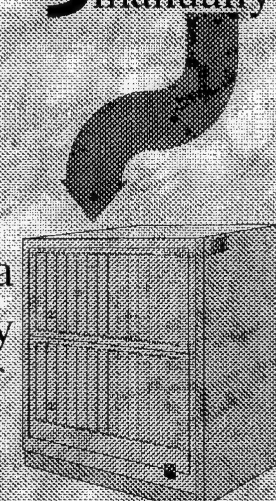
BACKGROUND

DATA SOURCES FOR THE ARMY HELLFIRE SRP:

- Environmental Storage Sites - Alaska, Panama, Yuma. Non-destructively baseline tested prior to storage. Visual inspection data and surveillance van test data collected annually.
- Component Testing - 15 missiles disassembled annually. All subcomponents tested. Repeated testing of electronic components at various environments, stresses.
- Flight Testing - 21 missiles flown biennially. Subjected to significant pre-flight testing.
- Surveillance Van - non-destructive testing of inventory and missiles in environmental storage sites. More than 20,000 individual missile tests performed.
- Propellant Analysis - six motors annually subjected to chemical/mechanical analysis.
- Missile Firing Data Reports - more than 1000 Army firings annually.
- Surveillance Data - ammunition condition reports (ACRs), Quality Deficiency Reports (QDRs).



Data was too extensive to manage manually...



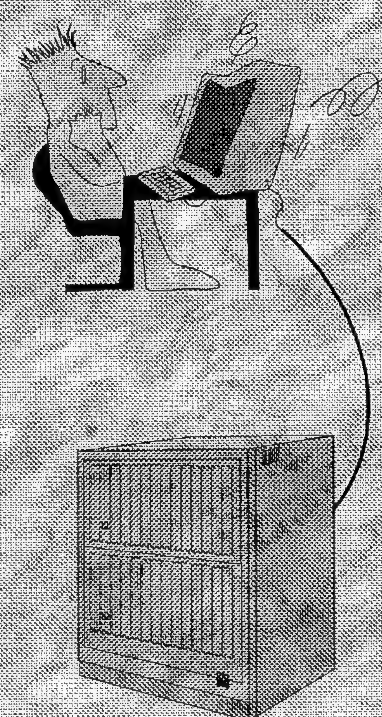
Data was input to a database. Currently over 3 Gigabits of space.

16 June, 1997

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

BACKGROUND



With the extensive amount of data in the database, we could now confidently analyze hundreds of electronic parameter trends. However, it was difficult/impossible to postulate how each trend, or a combination thereof would affect the system.

SIMULATION!

It was agreed that utilizing an existing simulation with modification could solve this problem.

16 June, 1997

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

MODIFYING THE SIMULATION

Teaming Approach:

- Simulation Programmers
- Systems Engineers
- Reliability (SRP) Engineers
- Test Engineers

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

MODIFYING THE SIMULATION

Step 1: Identifying potential parameters.

Test Engineers → Simulation Programmers

Provide review of all available test data to the programmers .

Identify test parameters that can be input directly to the simulation, and those that could be input with slight modification.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

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MODIFYING THE SIMULATION

Step 2: Determining focus of modification.

Simulation Programmers

Systems Engineers

SRP Engineers

Identify which of the potential parameters were important enough to warrant modification of the model:

- Parameters which could have significant impact on system performance,
- Parameters which would most conceivably degrade with age.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

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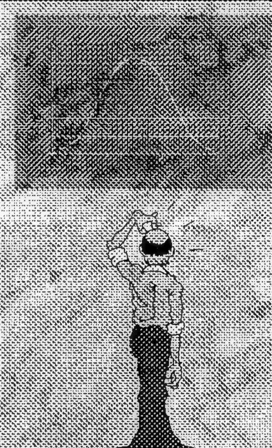
MODIFYING THE SIMULATION

Step 3: Validate & verify the model.

Utilizing the entire team, review the modified model. Compare simulation results to actual flight test data. Compare model to actual test data.

It was discovered that some means & distributions (M&D's) used in the original model were not consistent with actual hardware data.



Note: The original model had extracted M&D's from spec. values and "expected" distributions.

Actual data for 0-4 year old missiles was utilized to develop more representative means & distributions.

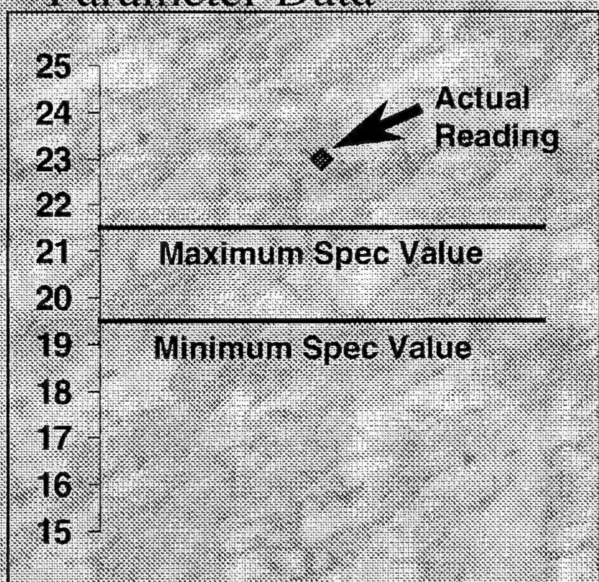
ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

BASIC APPLICATION TO SRP

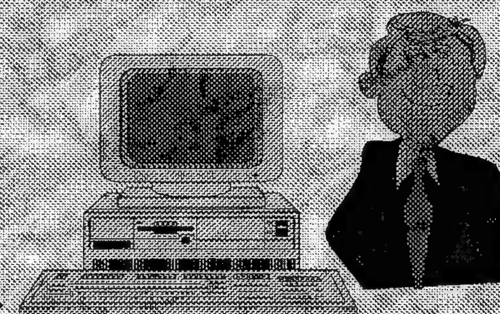
Application 1:

Parameter Data



?

How would actual missile performance be affected?



Perform simulation at various scenarios - range, offset angle, missile flight mode, and designation delay.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

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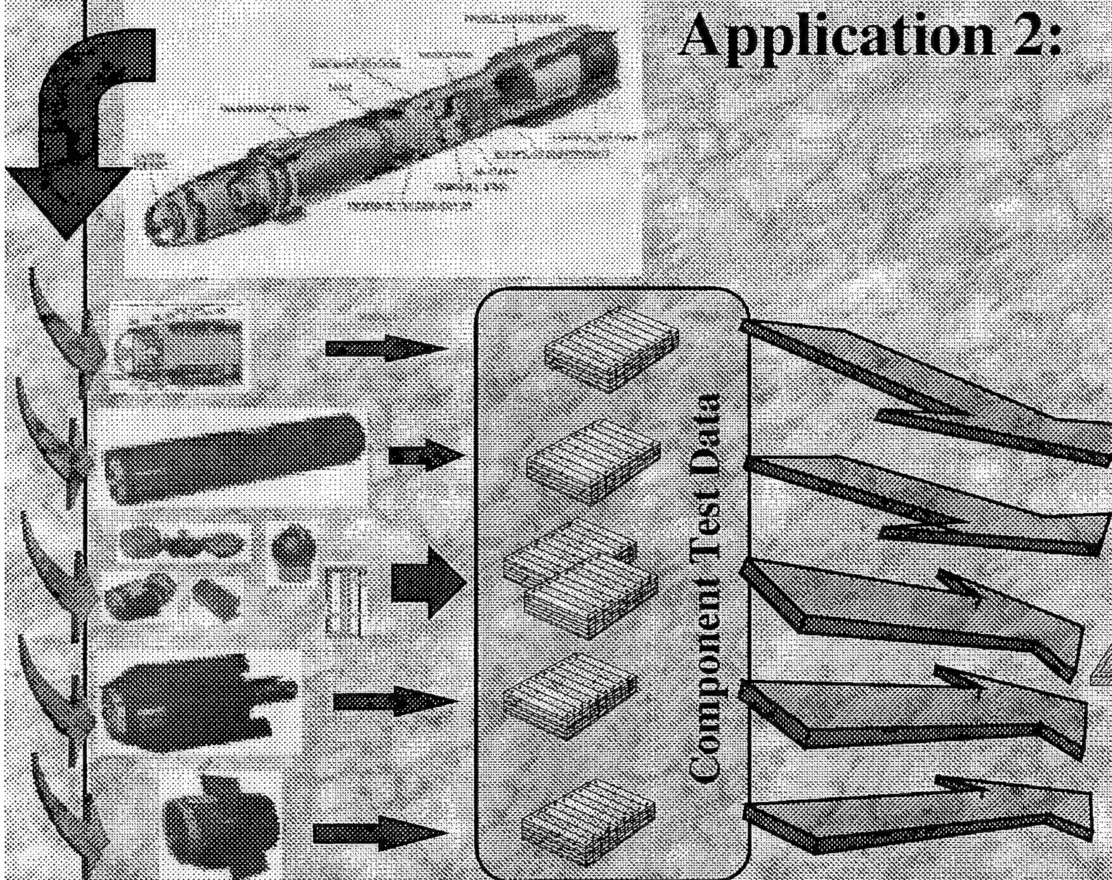
BASIC APPLICATION TO SRP

Application 2:



"Rebuild" missile in the simulation from its' component data to determine how it would have performed if actually flown.

Provided some satisfaction in determining the affect of a combination of out-of-spec readings.

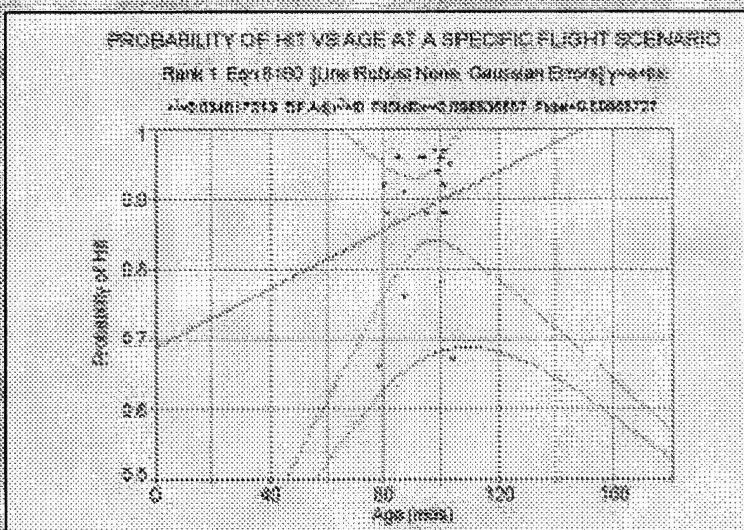
ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

BASIC APPLICATION TO SRP

Limitation of the Basic Applications:

The basic applications do not improve the ability to predict future performance.



Taking the simulated probability of hit for each "rebuilt" missile and plotting versus age for each flight scenario provides limited prediction capability. it also ignores the extensive amount of data in the database.

16 June, 1997

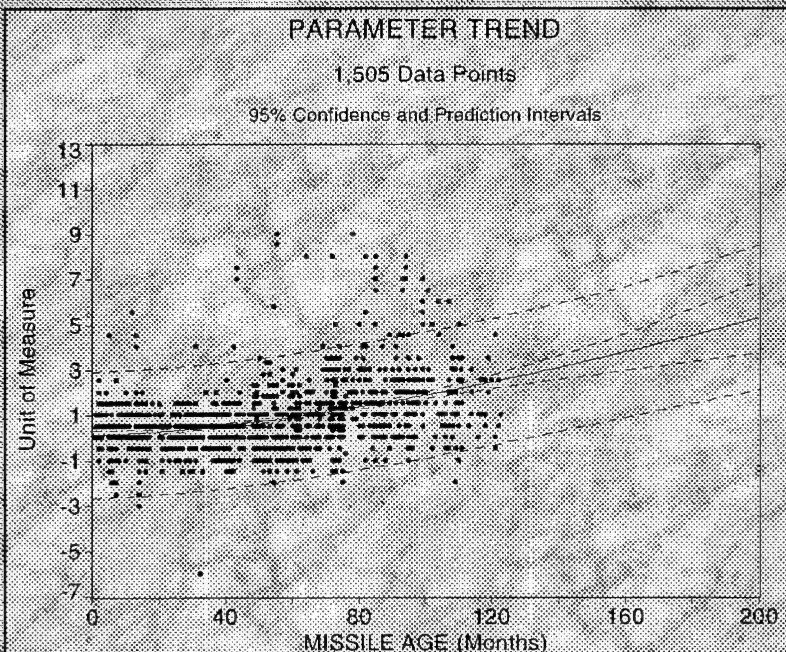
ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

DEGRADATION TREND APPLICATION

Step 1:

Start with the traditional SRP analysis approach, but using the extensive amount of data now in the database.



This yields statistically significant trends for many of the parameters.

Perform these analyses on all of the simulation applicable parameters.

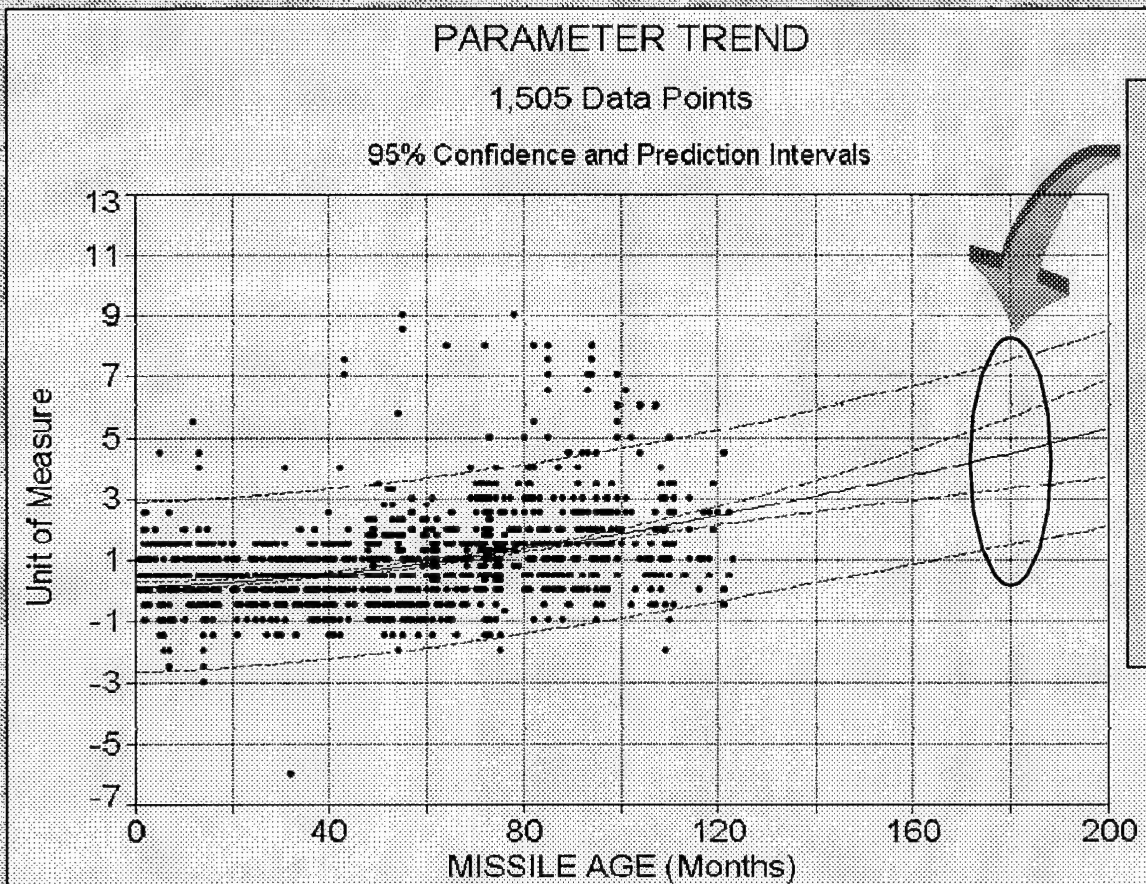
16 June, 1997

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

DEGRADATION TREND APPLICATION

Step 2:



EXTRACT ESTIMATE FOR PARAMETER MEAN AND DISTRIBUTION AT DESIRED AGE. INPUT THESE PREDICTED VALUES INTO THE SIMULATION FOR THIS AND ALL OTHER SIMULATIONS APPLICABLE PARAMETERS.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

DEGRADATION TREND APPLICATION

Benefits of using this methodology:

- Makes use of all of the available data.
- Identifies the affect of all parameters combined.
- Predicts future performance.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

LIMITATIONS AND CONSIDERATIONS

Limitations:

- Does not eliminate limitations of the traditional SRP analysis methodology.
  - ›Data filtering
  - ›Line fitting
  - ›Identification of trend mechanism
- There are some components which cannot be modeled well. Method is most appropriate for electronic parameters.
- Methodology of determining the predicted distribution is still being developed.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

LIMITATIONS AND CONSIDERATIONS

Considerations for systems in development:

- The higher fidelity the simulations model, the greater the capability. Subsystems modeled to subcomponents, subcomponents to each independent output.
- Hardware Design
  - Non-destructive testability.
  - Connector access to critical data streams.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

Utilizing Simulations for Performing Degradation Trend Analyses

SUMMARY

- The simulations model can be effectively applied to life cycle uses.
- For optimum results, plan for its' life cycle use during system development. This requires teamwork of various disciplines.
- The simulations model can be effectively utilized to support degradation trend analyses.
- Application of simulations models to life cycle requirements has significant potential for future development and growth.

ERIC E HUNT, CRE
(205)876-9566, RAMEngr@aol.com

A PC-Based Visual Munition Simulation System Using VisSim

by Larry E. Lewis

Air Force Research Laboratory/ Munitions Directorate (AFRL/MNGG)
Eglin Air Force Base, FL 32542 USA

JAWS Track: Joint SOS - SDT

Abstract

Development of technology for high performance missiles and bombs is becoming more and more dependent on effective simulations to provide information for making the best technology investments and to provide insights into potential performance of munitions incorporating such technology. With dollars and manpower in an ever decreasing spiral, it is more critical than ever to have available effective, easy to use simulations that can be rapidly configured to provide fast answers. Historically, such simulations have been cumbersome and difficult to modify. Fortunately, with increasing computer power and sophisticated commercial software available at low cost, it is becoming more possible to build remarkably effective tools within available budgets.

As part of the MSTARS (Munition Simulation Tools And Resources) project which supports development and analysis of new munition technology, a modular visual modeling system for simulating 6 degree-of-freedom (DOF) munition flyouts has been developed using the commercial tool VisSim. With reusable munition subsystem and other components, simulations can be rapidly built to test new ideas using both single and multiple run techniques. This paper presents the key elements of the simulation system and discusses the impact of using this type of visual system on the simulation & analysis process.

1. Analysis Requirements

At AFRL/MNGG, we are responsible for analysis of conceptual next generation guided munitions and the new technologies that will feed them. This analysis includes

- Determination of performance requirements
- Design tradeoff studies to identify high payoff munition concepts
- Technology tradeoff studies to identify which technologies will represent the best investments
- Identification of critical issues associated with munition concepts and technologies.

The ultimate purpose of MNGG analysis is to insure that the limited funding available for research and development goes to the highest payoff technologies, and that those

technologies transition as quickly as possible into the inventory of available weapons to help the warfighter.

To meet these requirements, a variety of analysis approaches are used. These range from back-of-the-envelope calculations to sophisticated simulations. In the analysis of guided weapons, dynamic simulations of weapon flight paths, or flyouts, are critical. Simple 3-DOF point mass simulations can answer many questions in the initial concept formulation phases, such as basic flight characteristics and gross performance potential. As concept formulation and evaluation continues, more fidelity is needed to generate accurate trajectories, determine better values for maximum velocity and range, and to conduct analysis of possible guidance and control schemes. This is a job for the 6-DOF simulation.

2. Tool Selection

Traditionally, 6-DOF simulations have been very labor intensive. Typically developed in a higher order language such as FORTRAN or Ada, they require much preparation and debugging time because the source code environment is very error-prone. Also, the final product is neither easily modified nor intuitive. Two common approaches to such traditional simulations are to either start from scratch to build a new simulation for every new modeling requirement or to try to build a massive "generic" simulation with hundreds of switches and options to try to do everything in one package. Neither choice is very appealing. In the former approach, nothing is reused, wasting much time and effort rebuilding models, not to mention the additional wasted time and effort spent in debugging. In the latter approach, it is sometimes possible to contrive examples for which a large generic simulation is useful, but more often than not, one winds up making extensive modifications which are made more difficult due to the large interconnected logic of the switches and options - more wasted time.

With shrinking budgets and personnel, simulation tools are desired that make it possible to do work better, with fewer people, and at lower cost. Such tools should be:

- Easy to use
- Easy to debug
- Capable of building reusable models
- Low cost
- Intuitive
- Fast executing
- Conducive to building models rapidly
- Flexible in handling different requirements
- Capable of handling complexity
- Effective in reducing errors

In recent years, there has been a move to visual environments for many software applications, from computer aided design (CAD) to banking programs. In the scientific and engineering analysis field, these include visual circuit design programs, visual mathematics programs, and visual control system design programs, among others. The advantage of visual tools over their high order language counterparts is that they meet more of the key requirements listed above, except that they are more expensive and sometimes have less flexibility - because they are tailored to a specific problem domain. However, if carefully chosen for the problem domain of interest, and if combined with other tools (spreadsheets, high order language programs, etc) to cover areas which they can't handle as well, then visual analysis tools represent the very best environment in which to do analysis work.

For 6-DOF simulation requirements, visual control system design programs are very attractive. The typical weapon system is comprised of a large number of systems that can be represented very well by visual construction in the control system domain. In addition, modern visual control system design applications have become increasingly sophisticated and are capable of handling much more than just control system type problems.

There are many excellent visual control system design tools from which to choose. These include MATLAB/ Simulink from Mathworks, MATRIXx/ System Build from Integrated Systems, Inc, and VisSim from Visual Solutions, among many others. At AFRL/MNGG, we use several of these tools in our work, including all of the ones previously mentioned. Each has areas in which it is clearly superior to the others and also areas in which it is inferior to the others. For our 6-DOF simulation work, we are interested in the PC environment and most available tools today support this environment. For the bulk of our 6-DOF simulation work, we chose VisSim because, in addition to meeting most of the capability requirements on our wish list (as did the other tools), it is lower in cost, easier and faster to use for this job, is capable of standalone operation not requiring a "parent environment", and has a nice feature for sharing simulation models with colleagues and customers who do not own the product (a special viewer). It is capable of incorporating external models developed in more languages than most tools allow (C, C++, FORTRAN, Ada 95, and Pascal), which makes it easier for us to incorporate existing legacy software from multiple sources and makes it more flexible for other organizations which work with us to interface their software to ours. It is capable of supporting multiple rate continuous integration models through code generation of model subsystems to create DLLs (Dynamic-Link Libraries) which run under Windows.

The focus of this paper is on the architecture of a 6-DOF modeling system which we have built using VisSim. The paper will also discuss how the visual environment has transformed the way in which we work.

3. The MSTARS Simulation System

The Munition Simulation Tools and Resources (MSTARS) project is a low budget in-house project in which we build and maintain the simulation tools needed for analysis here

at MNGG. Many simulation tools are used at MNGG, including a large number of FORTRAN simulations and a couple of Ada simulations. For reasons cited previously, there was a desire to move to a visual environment for our 6-DOF simulation work.

In March 1997, we built an initial prototype 6-DOF simulation using VisSim, and based on rationale described in the previous section, we decided to use VisSim as the environment for the bulk or our 6-DOF simulation work. Our desire was to meet the analysis requirements identified previously and also to build a work environment conducive to good team participation.

The PC was chosen as the computer platform for the MSTARS system. PCs have become so inexpensive and powerful in recent years that using unix workstations for our simulation work is no longer cost effective. We still have one Sun workstation for special purpose work, but the bulk of our simulation and analysis work is now done on PCs. Each engineer in the team has a 266 MHz Pentium PC and there is a standalone 200 MHz PC which serves as a repository for the MSTARS simulation component library. When new models are developed they are placed on the standalone PC for easy retrieval by team members. Simulation runs are conducted on each engineer's PC, allowing much parallel work to occur without slowing down the simulations.

The modeling system which has evolved over the past year is called the MSTARS Simulation System. It has already been used successfully to support both air-to-air and air-to-surface munition analysis, and is constantly being upgraded as required for new analysis needs.

Some important features of the MSTARS Simulation System include:

- Top level simulation diagram with easy to understand bitmaps for component access
- Modular organization of component library in Windows directories
- Simulation construction in hierarachical levels
- Uniform structure for component layout
- Model attribute values via external user defined file
- Model documentation built into the diagrams
- Easy swapping & modification of components
- External DLLs for a number of components
- Sample attribute files for each model component
- Various data file save options for analysis

Section 4 describes the MSTARS Simulation System architecture in more detail, elaborating on several key features of the system.

4. Basic Architecture

4.1. Top Level Components

In the MSTARS Simulation System, any number of different air-to-air or air-to-surface simulations can be built. The top level of a typical MSTARS simulation is shown below in Fig. 1. At this level are found the primary objects in the simulation, namely the munition, launch aircraft, and threat. It also includes facilities for setup, viewing terminal conditions, setting environment parameters, and viewing plot outputs. These objects are VisSim compound blocks which have appropriate bitmap images assigned to them.

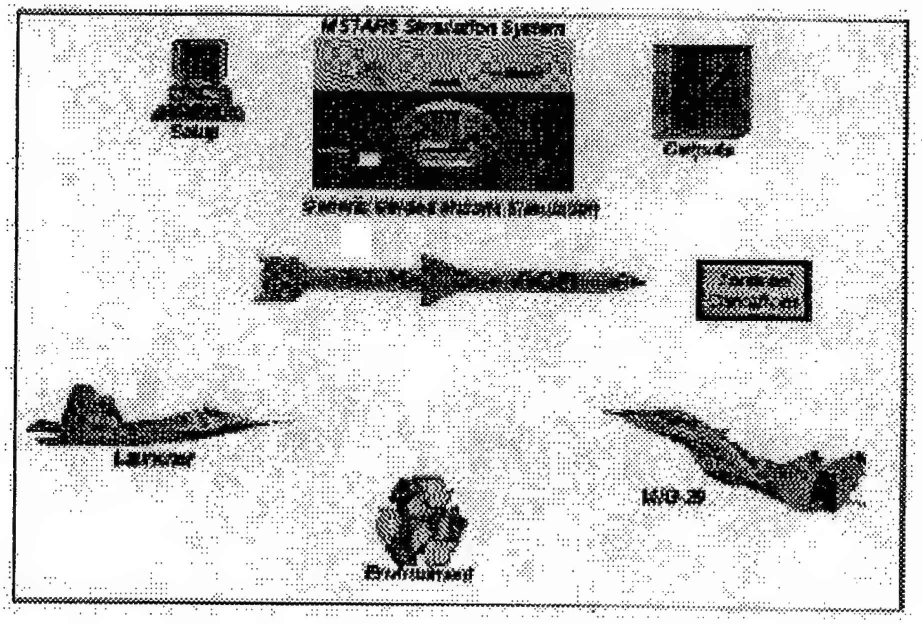


Fig. 1. Typical Top Level Diagram in an MSTARS Simulation

The Launcher is a launch aircraft, currently modeled as having an initial position and velocity with no maneuver subsequent to launch. Data link and umbilical models can be attached to the aircraft to provide these functions for scenarios which need them.

The threat in an air-to-surface scenario is either a fixed or moving ground target. Currently, the surface target models just provide position and velocity information for the target. Future upgrades will allow for IR signatures to be handled. Air targets have the same information plus acceleration definable in a flexible maneuver model. In addition, aspect dependent statistical and deterministic RF target signature models may be attached to a target model. Future upgrades will add IR signatures to this capability.

Since we are most interested in munition performance, the munition object (guided missile or bomb) is modeled in the most detail and will be described in the next section.

The Environment model at the top level is a global environment model which provides atmospheric or other global environment conditions for use by other simulation components. Currently, user defined air pressure is the only parameter provided by this model.

The Terminal Conditions block provides endgame information such as miss vector, miss distance, terminal velocity, and impact angles. These parameters differ somewhat between air-to-air and air-to-surface simulations.

The Setup block reads in simulation control settings (for monte carlo runs) and provides a simulation clock for use by other modules. This block could be modified to add other control options for the simulation as desired.

The Outputs block contains numerous plots and a disk output facility. A number of plot boxes have been created for several standard kinds of quick look assessments, and any number of new ones can be added by users as desired. Typically, each simulation will have some unique plot outputs. An example is shown in Fig. 2.

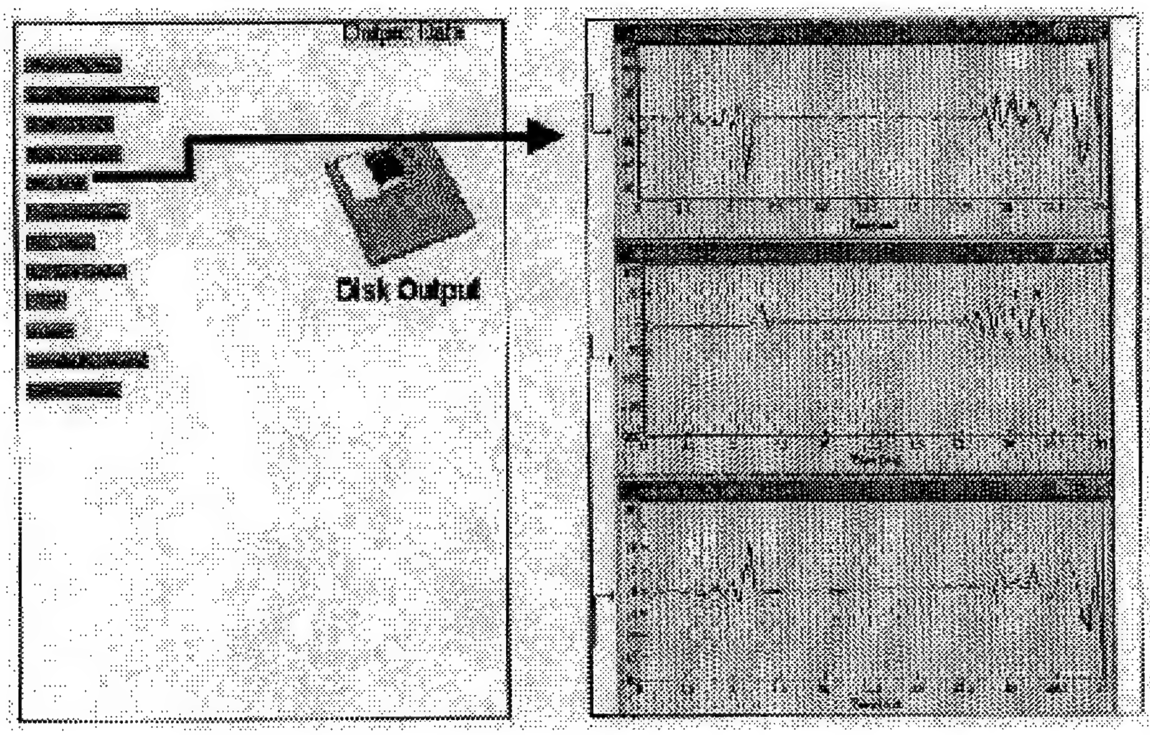


Fig. 2. Sample plot outputs

4.2. Munition Model

A munition model is designed for easy swapping of components for fast evaluation of new designs and algorithms. The top level of a typical munition model built using MSTARS components is a collection of icons allowing easy component access, as shown below in Fig. 3.

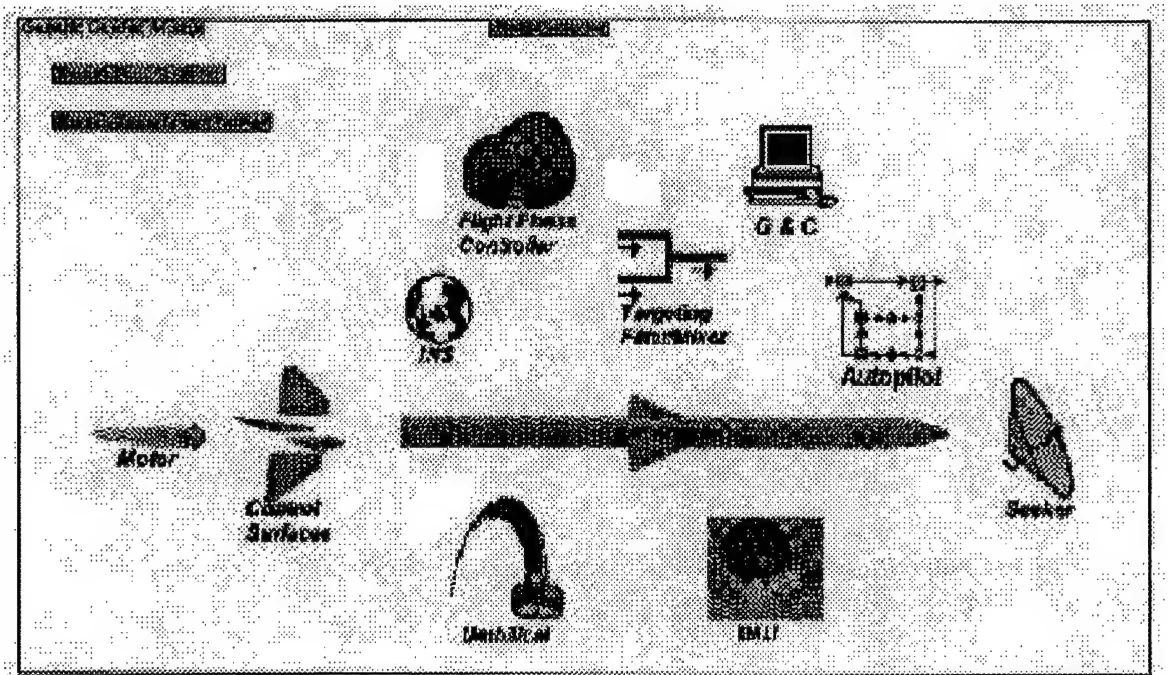


Fig. 3. Typical Munition Model

Each icon represents a VisSim compound block in which is found the complete subsystem model. It can be a high or low fidelity model.

The munition model in Fig. 3 can be used to illustrate an important simulation design choice - the use of VisSim global and scoped variables to make it possible to replace subsystems without wire connections. A VisSim global variable can be seen from within any diagram at any level in a simulation. A scoped variable can be seen at the diagram level where it is defined and in any diagrams contained within and below this level. Fig. 4 shows two different guidance models. These would be visible inside the G&C icon in Fig. 3. Note that the outputs of each guidance model are commanded body accelerations, but the inputs required by the two models are somewhat different. Inputs and outputs of a model at the level just below the munition level (Fig. 3) are accomplished by use of global variables. This means that one can swap any guidance model for another as long as the required inputs are calculated somewhere in the simulation. Guidelines for global names and where they are used have been developed for the simulation system. The primary output of a guidance module in this system is a vector containing body acceleration commands.

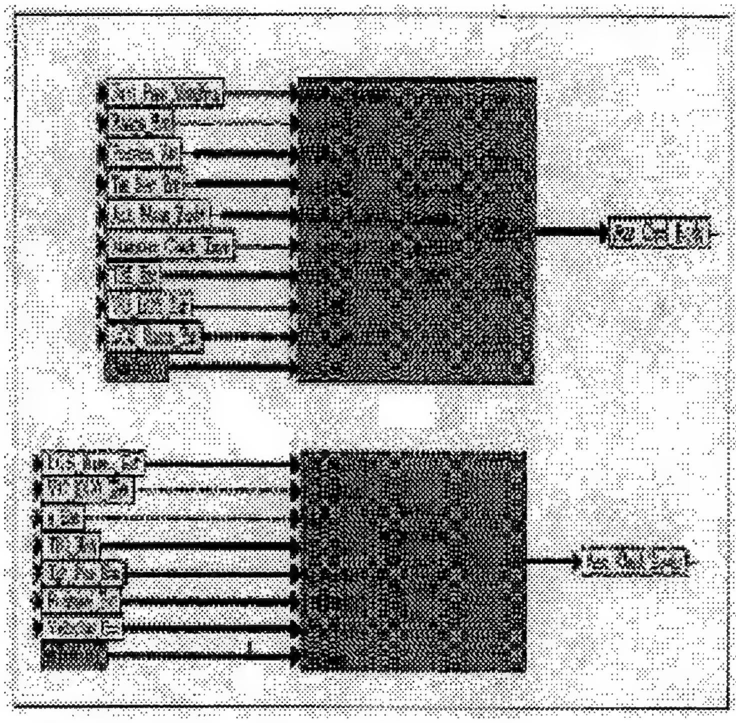


Fig. 4. Two interchangeable guidance laws in MSTARS

The result of this architecture is that any munition subsystem can be rapidly swapped for another. Subsystem models or the entire munition model can be swapped out by either cut-and-paste or by using VisSim Embed blocks, which are blocks that serve as pointers to diagram files. The latter is our usual method in the MSTARS Simulation System. The use of global variables should be minimized because there is a potential for variable name conflict since they can be seen anywhere in the simulation. For this reason, models residing at lower levels in the MSTARS hierarchy are designed to interface with wire connections rather than global variables.

One of the largest issues in modeling 6-DOF munitions for assessing new technology has always been the difficulty in modeling aerodynamic data which can be used for conceptual weapons analysis. Often, there is no wind tunnel data available because a physical model does not exist. In addition, there is usually a desire to make physical changes to the model as analysis continues, so the aerodynamic coefficients change as well. This often leads to autopilot problems because autopilots must be tuned to the aerodynamics. The problem of good aerodymamic data is not one for which there is an easy solution. We have used a widely available aerodynamic modeling program, Missile DATCOM, for much of our work but this tool is not suitable for all desired vehicle configurations. However the MSTARS Simulation System has taken two steps which make the general problem of aerodynamic modeling a bit easier:

- Creation of a standard set of aerodynamic coefficient table structures so that any source for aerodynamic data can be put into a common format.

- Development (still in progress) of aero-adaptive autopilots which respond to changes in aero coefficents during a simulation without re-tuning (or with minimal re-tuning).

4.3. General Component Layout

Designing a modeling system which can be used by a team of diverse engineers is very challenging. There is a tradeoff between allowing creativity and forcing consistency. We've chosen a middle ground where model consistency is good but not too limiting on the creative process. A typical subsystem model, a control surfaces model, is shown in Fig. 5.

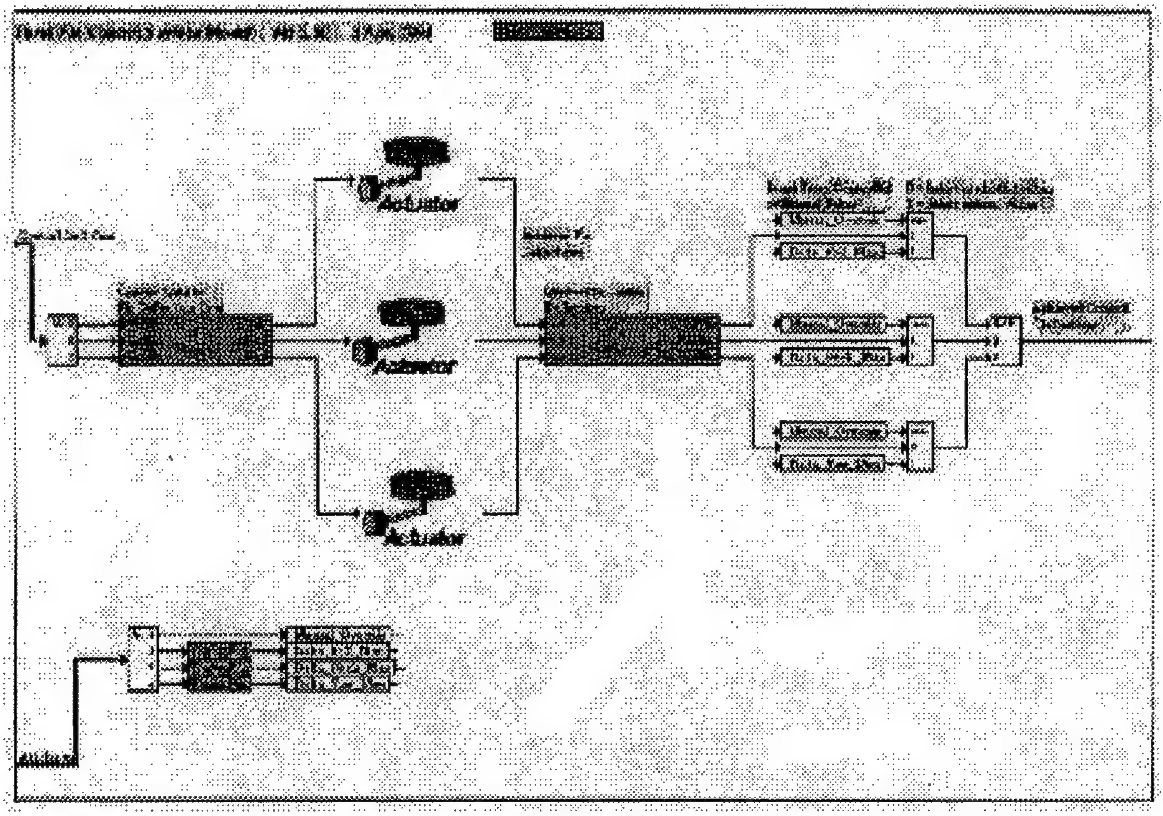


Fig. 5. Control Surfaces Model

Several characteristics of typical MSTARS model layout can be seen in Fig. 5:

- Title, date, and version number
- Model description block containing useful model information
- User-defined model attributes, set externally and wired into the model. This allows attribute setting to be changed without affecting the ability to compile the diagram using the Visual Solutions C-code generator

- Labeled wire connectors where needed
- Color coded comments where appropriate
- Vector inputs and outputs to save space

The Model Description block in Fig. 5 is especially important, because one goal of the MSTARS system is to include documentation inside the model to the extent possible. Inside the description block are comment blocks as illustrated in Fig. 6.

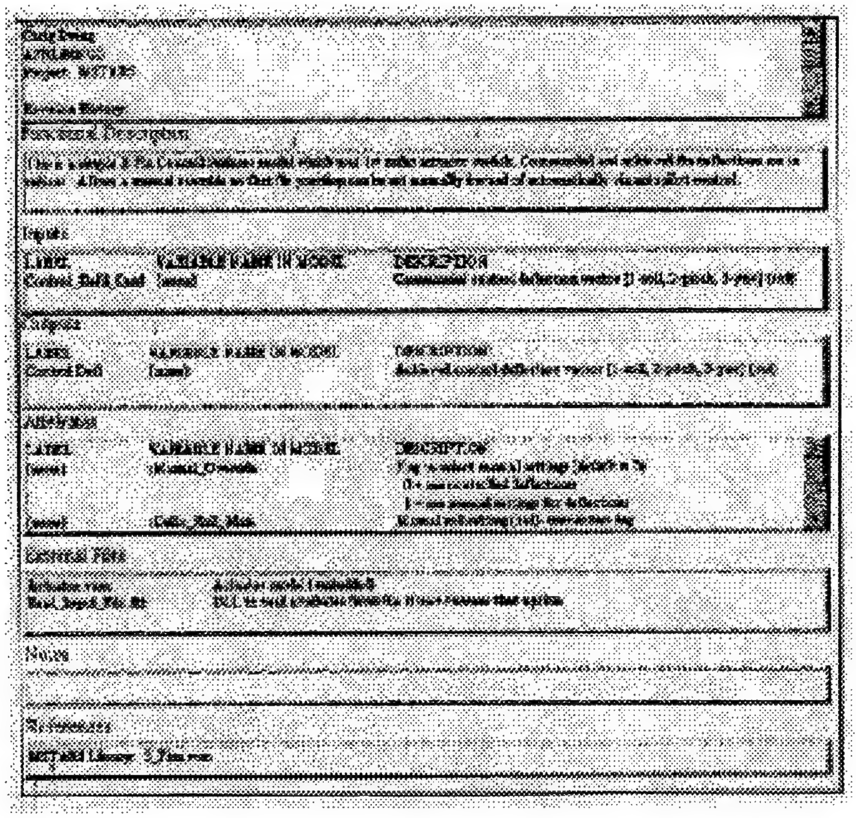


Fig. 6. Comments included in Model Description block

The comment blocks provide useful information such as author, revision history, inputs, outputs, attributes, any relevant notes and references.

4.4. Data I/O

Data input/ output is a challenge for any modeling system. Complex flexible data journaling can be very time consuming. We've taken a simple approach in the MSTARS Simulation System which is fast, yet meets most normal requirements for I/O. It will be expanded in the future as needed.

Each model can have a set of attributes which are constant for a simulation run, but may change from run to run and from run set to run set if Monte Carlo simulations are being

executed. In the MSTARS Simulation System, this is accomplished by use of an input file containing the attribute values and also statistical information for Monte Carlo simulations (see section 4.5 for more information on how Monte Carlo simulations are accomplished). The input file is read by a special C++ program compiled as a Windows DLL. Each component information block has a special identifier and can be placed anywhere in the file. Fig. 7 shows a sample portion of a simulation input file.

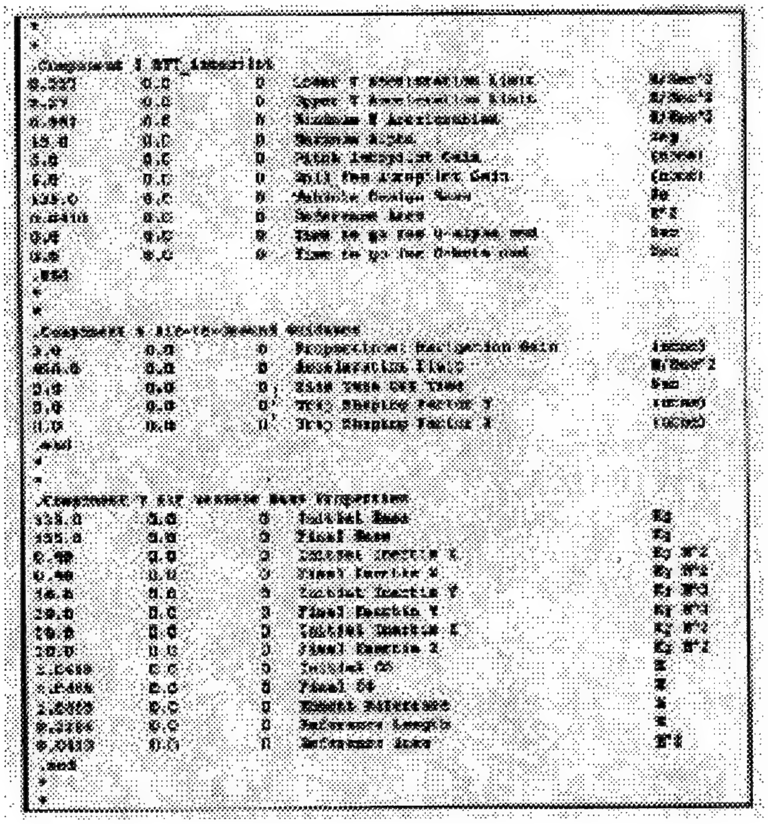


Fig. 7. Portion of a typical input file

For data output, a combination of standard VisSim Export blocks and external DLLs are used to accomplish various kinds of data saves. VisSim Plot blocks are used for quick-look analysis and a special MSTARS C++ DLL saves formatted summary information for each run and run set. Unformatted ASCII data, arranged in columns, is saved via VisSim Export blocks for loading by external programs such as MS Excel, or a number of lethality programs which analyze warhead effects and calculate probability of kill (P_k).

4.5. Monte Carlo Simulations

Monte Carlo simulations are extremely important for many problems in weapon analysis, especially for generating kinematic footprints (boundaries of air-to-surface munition kinematic flyout range) and determining miss distance statistics. They are also

important in identifying cause and effect relationships between design parameters and munition performance.

In the MSTARS Simulation System, the input file (Fig. 7) contains information necessary for conducting Monte Carlo runs. The three columns of data in the input file contain the parameters for each model attribute. The first column contains the nominal, or mean, value for the attribute. For the case where no randomization is desired, this is the only value used. The third column is an integer indicating randomization type. Currently, there is capability for gaussian and uniform distributions, as well as user defined types. For gaussian distributions, the second column indicates the standard deviation. For uniform distributions, the second column indicates the lower bound of the distribution. If the distribution is user-defined, the set of values are provided in separate files.

Randomization is accomplished by passing the input file data through a randomization block, executed only at the start of the simulation. This is shown in Fig. 8.

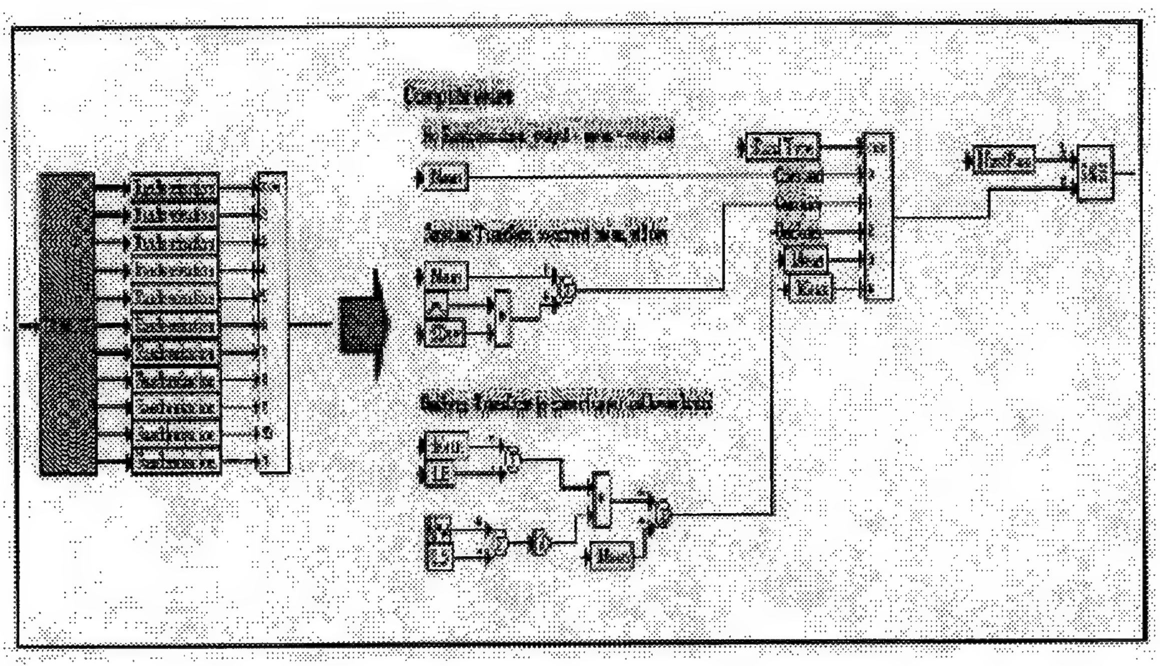


Fig. 8. Randomization of model attributes

On the left side of Fig. 8 is shown a DEMUX block which takes the entire set of attributes from the input file as a single vector and pulls off the set of 3 parameters (mean, std dev, randomization type) for each attribute. The example in Fig. 8 is for a component with 6 attributes. The right side of Fig. 8 shows the heart of the randomization block, where a single value is generated based on the user specified randomization. Note that if the randomization type = 0, this means no randomization is done and the "mean" is returned.

As a result of the MSTARS randomization architecture, any attribute of any model in the simulation can be specified as a Monte Carlo parameter for run-to-run variation and for run set to run set variation.

4.6. Use of DLLs

One very useful feature of VisSim is its ability to import external programs or diagrams which have been "code generated" into C-code. In either approach, a Windows DLL is created which can be imported as a User Function block. These two approaches are described below:

Externally Developed User Functions:

User functions can be written in practically any language for which a compiler exists that can generate a Windows DLL. Most common compilers fall into this category. At MNGG, we have created DLLs in FORTRAN, C, C++, and Ada 95. According to Visual Solutions, Pascal can also be used.

The use of external DLLs allows for:

- Reuse of legacy code that would otherwise have to be converted to a diagram
- Creation of special purpose utilities
- Creation of models which, for one reason or another, are more easily developed in a language environment.

The MSTARS system has DLLs representing each of the above types. Special DLLs were created for data I/O. Existing FORTRAN and Ada code has been imported into the system. And new models have been developed in C and C++.

Code Generated Diagrams:

A source code generator is available from Visual Solutions which can be used to selectively generate C-code for all or part of a model represented in a VisSim diagram. This code can be compiled as a DLL so that it can be imported into a diagram in place of the diagram-based model or it can be compiled as a separate executable program. Use of DLLs coded from a diagram based model serves two basic purposes:

- It speeds the model up significantly
- It allows creation of multi-rate simulations where even continuous integrations can be done at different rates in different models

4.7. Multiple Rate Simulations

As simulations become more complex, it becomes very important to be able to simulate each subsystem at its own rate, which may or may not be the same as the simulation update rate. This is done primarily to speed up the simulation and to model simulation rates for an actual subsystem.

There are three ways to get the effect of multiple subsystem rates:

- For discrete or hybrid subsystems which have discrete delays and integrators, these are simply simulated using VisSim discrete blocks set at the appropriate time step.
- For subsystems which have continuous Laplace-domain integrators (1/S blocks), multiple rates can be achieved using the code generator (a separate Visual Solutions product) on the subsystem. The coded version runs at the rate which was set at the time code generation was accomplished. It runs at this rate no matter what the simulation time step, if incorporated back into a VisSim diagram.
- For the general situation of update rates not requiring integrators, the best approach is to use the enabled subsystem feature (VisSim Beta version 3.5) to accomplish triggering a block at the desired update rate. An example is shown below in Fig. 9. In this structure, the Attributes block reads in model

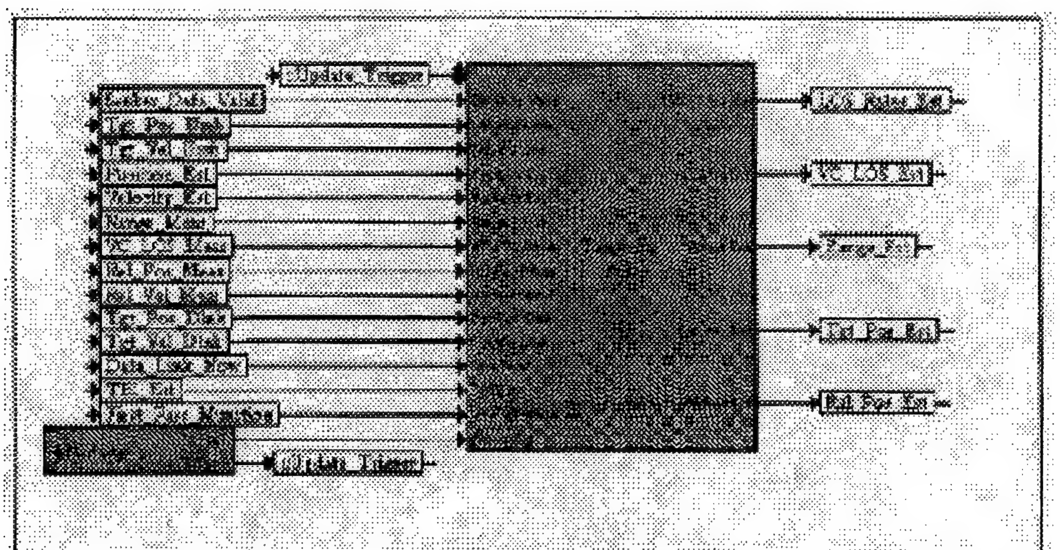


Fig. 9. Targeting Filter illustrates triggered block approach

parameter data from an input file as usual. One of those parameters is update rate. A pulse train trigger (inside Attributes block) is created and saved in the scoped variable ::Update_Trigger and this is used to drive the enable connector (connector at top left of diagram) for the compound block. Using this approach, the same trigger variable is also available to lower level components inside the block diagram which may have discrete blocks that need to run at the same rate.

By using a combination of these three techniques, we can achieve a variety of multiple rate configurations needed for analysis.

4.8. Windows Directories

The last aspect of MSTARS Simulation System architecture which will be covered here is the use of the Windows system itself as part of the architecture.

Many modeling systems contain elaborate special purpose dialogs and tools for selection of models and accomplishing various tasks. These are very nice, but require much time and effort to develop. If the modeling system changes, the special purpose graphical tools must change as well. MS Windows has many built in features which can be used to great advantage without resorting to special purpose dialogs and requires no extra effort. In the MSTARS system, directories are arranged to logically organize components according to type and function. Sample input files are provided in each directory containing a model which can be cut and pasted into a large input file containing attributes for many models. Double clicking a model or simulation brings up VisSim and automatically loads the model. Notepad and Write are used extensively in creating input files and data files.

By making use of features already built into Windows, much time and effort was saved over building special purpose interactive dialogs.

5. Impact On Simulation & Analysis Process

Having a visual environment for creating models and conducting analysis has a profound impact on the way work is accomplished Some examples in particular:

- Simulation parameters such as integration type, time step, and various runtime options can be set from a menu, saving tremendous time over manual techniques
- The merits of a particular model architecture can be inspected visually in seconds instead of spending much time sifting through pages of source code
- Building modes hierarchically from a component library consists of cutting and pasting with a mouse rather than laboriously writing call statements in a source code program

- An intuitive environments results in more time for creative thinking about the real engineering issues instead of worrying about source code architecture
- Fewer errors are made due to intuitively obvious visual connections
- Very rapid swapping and testing of new ideas can be accomplished compared to the source code environment.
- There is a greatly enhanced ability to share models and ideas with colleagues who can very quickly understand the big picture. This is not possible with a huge compiled language program because the parts are scattered over possibly hundreds of pages of code
- Debugging is quicker in the visual environment because of features built into the commercial tools, such as color coded blocks indicating errors, ability to instantly see parameter values using the mouse, and easily tracing signal paths through a simulation.

To further compare use of the visual environment to use of a typical source language environment, it is illuminating to look at the typical process involved in developing a model of a new munition and doing comparative trade-off studies for a new technology subsystem such as a seeker. In the source language environment, the process might work something like this:

- Complete a new simulation of the munition or try to configure an existing munition
  simulation for the work (several weeks to several months).
- Debug the munition simulation (several days to several weeks)
- Add features which were neglected in the initial design (several days to several weeks)
- Develop a model of the new subsystem (several days to several weeks)
- Integrate the new subsystem into the munition simulation and debug (several days to several weeks)
- Debug the new simulation (several days to several weeks)
- Conduct simulations of munition performance for new versus old subsystem (several days)

For the visual environment with reusable components, the same process might look like this:

- Use the component library to build a prototype munition similar to the desired munition (several minutes)
- Conduct analysis using the prototype munition model to determine additional features needed (several minutes to several hours)
- Build the new features into the new simulation (several hours to several days)
- Debug the simulation (several minutes to several hours)
- Use the component library to select a subsystem model similar to the new subsystem (several minutes)
- Conduct analysis using the simulation to determine requirements for the new subsystem model (several minutes to several hours)

- Add features to the existing subsystem model to create the new one (several hours to several days)
- Integrate the new subsystem into the munition simulation and debug (several minutes to several hours)
- Conduct simulations of munition performance for new versus old subsystem (several days).

Note that there seems to be more steps in the visual environment, but the total time for a typical project is typically measured in terms of days and not months as compared to the source code environment. The additional steps come as a result of the capability for "rapid prototyping" which makes it possible to build something quickly and interate on the design until it works as desired. An important factor in the effectiveness of the MSTARS Simulation System is a reusable library of components. This is certainly an advantage in a source code environment as well, but it is not as effective or fast as the visual environment because it is less intuitive.

The net effect of the MSTARS Simulation System over previous simulation approaches used at MNGG is that it has drastically improved the process of simulation and analysis: It is faster, more effective, and requires fewer resources.

6. Summary

AFRL/MNGG has constructed a visual 6-DOF munition simulation system under the MSTARS project using the commercial visual design tool VisSim. The MSTARS Simulation System has a library of reusable components and enables rapidly building new simulations of guided bombs and missiles in minimal time. At this time, there are about 70 models in the component library which can be used in building munition simulations. New models are being added almost weekly as needed to perform required analyses.

The visual environment has drastically changed the way in which conceptual weapon simulation and analysis is conducted. Much more time is spent in understanding and solving engineering problems instead of focusing on complex simulation software code.

With all the advantages, there are also some disadvantages of the visual environment:

- When it comes to complicated logic, it is often easier to create the intended effect in a language enironment because there is complete flexibility in creating logic structures. However, this situation is changing and most visual tool makers are putting mechanisms for decision logic in their tools. Also, the ability to import external programs into visual environment means that each environment can be used in the areas for which it is best suited, and a single visual-based simulation can be built combining the external programs and visual diagrams

- Complex data structures can be represented better in a high level language (especially Ada 95 and C++). Usually this is not a critical issue for most problems of interest.
- Speed may be an issue depending on the application. Diagrams are interpreted and run slower than a comparable model developed and compiled by a traditional computer language. However, code generation of a diagram can produce code which is several times faster and can approach the speed of a traditional compiled program

We believe the tradeoffs swing in favor of the visual environment. The advantages far outweigh the disadvantages.

The MSTARS Simulation System is undergoing constant change as we at MNGG learn new and better ways of doing things and as the need for additional models and new capability continue to grow. We believe the approach which was taken a year ago in building this visual environment was the right approach for our problem domain, and we continue to improve it to handle more and more complex problems.

CNS / ATM with DUAL USE AVIONICS

CDR Kurt Engel, USN
PMA-209E
(301) 757-6765
engelkr.ntrprs@navair.navy.mil

Mr. Garth Van Sickle
DCS Corporation
(301) 862-2390x286
gvansick@dcscorp.com

ABSTRACT

Changes in global civil airspace architecture, commonly called Communications, Navigation, Surveillance, Air Traffic Management (CNS / ATM) will necessitate changes in military avionics equipment and air traffic service provider procedures. The military must work closely with civil authorities as these concepts are developed. For tactical aircraft, the possibility of installing unique equipment to capture this civil functionality is unacceptable because of weight, space, and cost considerations. For some of the communications issues, the same AN/ARC-210 radio the military is installing for its digital functionality has a growth capability to handle the civil 8.33 kHz channel separation and civil VHF Data Link Mode II and III. Likewise, the military GPS receivers, EGI and MAGR, will have a growth capability to achieve the integrity and Required Navigation Performance (RNP-4) for flight in the National Airspace System (NAS) and international controlled airspace. For the required civil surveillance functionality, the dual use solution has not yet been identified. The solution for some aircraft might be the civil use of Joint Tactical Information Distribution System (JTIDS) information for air traffic monitoring through gateways. Another possibility for a dual use solution might be the installation of Mode S in military aircraft for Automatic Dependent Surveillance Broadcast (ADS-B). With this solution, an upgrade to the AN/APX-100 could be the path to capture this new functionality and at the same time explore the possibility of a military utility of broadcast surveillance architecture. Either way, the dual use of each aircraft's 1553B data bus and cockpit electronic displays will support both civil and military utility.

INTRODUCTION

The tremendous growth in air traffic presents increasing challenges for air traffic service providers, general aviation (GA), military aviation, and commercial air carriers. Such growth is straining airspace and airport resources. The current air traffic system requires significant upgrades in order to increase flight efficiency and system capacity while continuing to meet flight safety standards. The International Civil Aviation Organization (ICAO), Federal Aviation Administration (FAA), and other civil aviation authorities (CAA) plan to implement a new air traffic architecture to meet this need. This new architecture takes advantage of emerging technologies in communication (data links), navigation (direct routing) and surveillance (self-reporting with cockpit displays of traffic) to improve air traffic safety and efficiency. The goal is to transition to "free flight", a concept of flying with less restrictions and more cockpit situational awareness. Free flight will give operators the freedom to choose direct routes, speeds, and altitudes, in near real-time, thus providing greater operational efficiency while raising safety to the next plateau. The Future Air Navigation System (FANS) committee of ICAO led the way with the implementation of FANS architecture in the Pacific. ICAO refers to this new functionality as Communication, Navigation, Surveillance, Air Traffic Management (CNS/ATM). The USAF refers to these new concepts as Global Air Traffic Management (GATM).

The requirements for CNS / ATM are derived from draft implementation plans, ICAO Standards and Recommended Practices (SARPS), RTCA Minimum Aviation System Performance Standards (MASPS) and Minimum Operational Performance Standards (MOPS), the Airlines Electronic Engineering Committee (AEEC) ARINC Characteristics and Standards, Aeronautical Information Circulars (AIC), etc. The time line for implementation of this new functionality varies from region to region with most of the near term issues focused in the North Atlantic air routes and European airspace. Within military aviation, transport aircraft will be impacted first and most of the military effort to date has been focused on transport type aircraft.

For tactical military aircraft to operate in this new environment, significant modifications to existing aircraft could be required. The civil avionics required to achieve CNS functionality could have a significant negative impact on the military mission of these aircraft. Likewise, the tight fiscal climate deters avionics upgrades that do not make a positive contribution to the aircraft's warfighting mission. There are few nonmaterial alternatives available for military aircraft that fly in controlled airspace. It is expected that non-compliant aircraft will receive handling delays or non-optimal routes and/or altitudes. The efficiency of the military aircraft's passage through controlled airspace will be degraded and in some cases, the aircraft will be excluded. Tactical military aircraft will continue to fly in restricted areas, warning areas, and international open ocean airspace under the "due regard" option which obligates the military aircraft commander to be his own air traffic control agency and to separate his aircraft from all other traffic. For due regard flight in instrument meteorological conditions (IMC), a military air

traffic service provider must provide flight following. However, if the aircraft is to cross into sovereign controlled airspace, the CNS capability specified for that airspace will prevail and compliance will be expected.

COMMUNICATIONS

With the implementation of CNS/ATM transoceanic routes, where radar following is not available and over the horizon flight following is cumbersome, routine pilot-to-controller voice communications will be augmented by data link transmissions. Just as an E-Mail is a different form of communications than a phone call, data links to aircraft will introduce new functionality not available over voice communications. Even though voice connectivity will always be required, as navigation accuracy increases and aircraft separation requirements decrease, data link functionality will become mandatory. A primary objective of the CNS/ATM system is to reduce the traffic separation standards. This will mandate a more responsive voice and data link communications capability. The air traffic service providers will need real time connectivity with trans-oceanic traffic for routing changes, weather avoidance, etc. For overland and line of sight operations, where radar following and VHF real time connectivity is standard, the limiting factor for handling the growth in air traffic is the limited radio frequency (RF) spectrum available. Current plans to increase the spectrum capacity are to utilize reduced channel separation and Time Division Multiple Access (TDMA) architecture.

COMMUNICATION SYSTEM COMPONENTS

Communications system components for trans-oceanic passenger aircraft include satellite communications (INMARSAT, IRIDIUM, etc.) and/or high frequency data link (HFDL) radios with state of the art communication management units (CMU). Data link requirements will be mandated by region, with Controller to Pilot Data Link Communications (CPDLC) being the ultimate goal. Most tactical aircraft will have little use for this trans-oceanic functionality. However, tactical aircraft will need to be upgraded to handle the reduced channel separation capability, VHF data link capability, and VHF TDMA architecture.

SPECIFIC COMMUNICATION REQUIREMENTS

EUROCONTROL intends to increase spectrum capacity by reducing channel separation from 25 kHz to 8.33 kHz frequency spacing as a near-term fix to their frequency congestion problem. This requirement will be implemented January 1, 1999 in the core of Europe for the upper airspace (country dependent: above FL245 in most countries except for France, which used FL195). It is planned to migrate to lower altitudes as early as 2003. For the long-term solution to the overall VHF frequency congestion problem, both the US and Europe endorse the use of emerging TDMA technologies.

The near term civil utility of VHF data links will be to facilitate weather, both text and graphical, flight service information, and aeronautical information between aircraft and ground systems. An office worker can get a weather map via the Internet for his/her monitor with a few keystrokes and someday, aircrews will be able to import graphical weather of their destination airfield. Also, Notice to Airman (NOTAM) and Automatic Terminal Information Service (ATIS) will arrive via data link upon request. The ultimate goal of CPDLC will be implemented with a series of software modifications as the requirements mature. Just as modern business has found network-centric computing very useful, tactical military aircraft will find VHF data links very useful for civil functionality and network-centric warfare.

Military tactical aviation has a long history of UHF communication. Civil air traffic service providers installed UHF radios specifically to provide military aircraft traffic services while they were operating in controlled airspace. Although this procedure of talking to civil aircraft on VHF and military aircraft on UHF was workable, it introduced some safety issues since the VHF users and the UHF users operating within the same sector could not hear each other's radio transmissions. At the present time, military aviation is transitioning to digital programmable advanced communications systems with functionality from 30 to 400 MHz frequency range. These radios are being installed to meet the warfighting requirements of tactical aircraft but are capable of capturing the civil functionality with minor modifications. The Navy's AN/ARC-210 radio, with military data link capability, is lightweight and suitable for installation in any military platform. With over 1500 already installed and plans for the purchase of over 3000 systems, the AN/ARC-210 program manager has initiated an upgrade effort to capture the civil 8.33 kHz VHF channel spacing as well as civil VDL mode II and III. With these minor modifications, this military radio will be interoperable with the civil air traffic service providers throughout the world. If CPDLC eventually becomes a military requirement, software upgrades to the communication system's processor will capture this functionality. This is an excellent example of meeting the needs of CNS functionality with minor upgrades to a military radio. For communications, dual use avionics appears to be a cost-effective solution.

NAVIGATION

In the CNS air traffic environment, navigation standards will be defined as Required Navigation Performance (RNP). Today, civilian navigation equipment is certified with a Technical Standard Order (TSO). When the equipment is properly installed in an aircraft, the aircraft is given a Supplemental Type Certificate (STC). This certification is based on the demonstrated functionality of the equipment and the approved installation within that aircraft. With the introduction of area navigation (RNAV), the aircraft's navigation solution is probably the product of several sensors and single box certification is no longer appropriate. The entire navigation system must be evaluated and certified. This certification process brings new emphasis on Flight Management Systems (FMS) and the associated software. The first aircraft to be certified for RNP was the 747-400.

NAVIGATION SYSTEMS COMPONENTS

RNP functionality requires an aircraft to be capable of RNAV and with the navigation accuracy to maintain its position within a specific number of Nautical Miles (NM) of its cleared track. The aircraft must be able to maintain this specified cross track containment 95% of the time for the duration of the flight with an assurance of 99.999% that no undetected excursions beyond 2 x RNP will occur. This accuracy error budget includes positioning error, flight technical error (FTE), path definition error, and display error. Differing levels of RNP accuracy will be specified for different airspace and regions, and will be implemented under different timelines. Trans-oceanic air routes in the Pacific have already been designated for RNP 10 and all trans-oceanic routes are scheduled to be designated for RNP 4 by 2003. Continental Europe introduced Basic Area Navigation (BRNAV) on April 23, 1998. BRNAV is equivalent to RNP of 5 NM. They chose RNP 5 to ensure that Global Positioning System (GPS) receivers would not be required. During 1998, EUROCONTROL will decide whether or not to progress to Precision Area Navigation (PRNAV) which is equivalent to RNP of 1 NM for some specified airspace and terminal areas after 2005.

System performance standards for RNP are divided into two categories: technical performance requirements and functional capability requirements. The technical performance requirements dictate the accuracy, containment integrity, and containment continuity (availability) performance of the navigation system. The functional capability requirements define the features the navigation system, as a whole, must possess in order to fly in RNP airspace. These functional capability requirements include, but are not limited to, a FMS, displays, interfaces, controls, steering and procedural functions, and alerting. All system technical performance requirements and functional capability requirements must be met for the aircraft to operate in RNP-4, or less, airspace.

SPECIFIC NAVIGATION REQUIREMENTS

In order to operate in a RNP-4 or less airspace, aircraft will require an integrated GPS receiver and RNAV functionality. These aircraft also must be capable of electronic data transfer and have available a certified digital database of flight information. Civil Standard Positioning Service (SPS) GPS users have spent years trying to remove the impact of the Selective Availability (SA) errors intentionally introduced by the military GPS control segment. To ensure the introduced SPS position and time errors do not impact safety of flight; civil authorities have mandated tight standards of SPS GPS accuracy, continuity, availability and integrity. The Wide Area Augmentation System (WAAS), funded by the FAA, is specifically designed to increase the quality of SPS GPS for use in civil aviation. Local Area Augmentation System (LAAS) is another way to remove the SA errors with differential GPS.

Tactical Military aircraft use Precise Positioning Service (PPS) GPS and are not effected by SA since these aircraft use keyed encryption devices to remove the errors. Also, the two frequency P(Y) code signal used by the military is much more robust than the single frequency

C/A signal presently used by civil users. Although significant work is yet to be done, the GPS modernization program plans to demonstrate unaugmented PPS GPS with sufficient accuracy, availability, continuity, and integrity for world wide non precision approach and Category I approaches and landings. Tactical military aircraft equipped with Inertial Navigation Systems (INS) coupled with PPS GPS should have little problem meeting the requirements of RNP 4.

The 1994 Defense Authorization Act directed the installation of tactical GPS receivers in all military platforms by September 30, 2000. However, the GPS user equipment installed in most tactical aircraft today does not meet the integrity standards for RNP 4 certification. Likewise, the presidential decision to turn off SA by 2006 has forced the military to find a new way to ensure a military utility of GPS information. This new effort is called GPS Modernization / Navigation Warfare (NAVWAR) and will probably require an upgrade to today's 5-channel GPS receivers. Tactical military aircraft will be able to capture RNP 4 functionality and dual use utility with the integrated installation of the upgraded GPS Modernization receivers. The upgraded Embedded GPS INS (EGI) and the Miniature Airborne GPS Receiver (MAGR 2000) should both contain all-in-view receivers and meet RNP-4 integrity standards. The certified digital flight information database is in work and prototype integrations are planned to demonstrate both non-precision approaches (NPA) and Category I precision approaches. This will be another example of achieving CNS functionality with minor upgrades to military equipment. For Navigation, dual use avionics is again the most cost-effective solution.

SUVEILLANCE

Air traffic surveillance today is based on primary radar and L-Band (1030 & 1090 MHz) Secondary Surveillance Radar (SSR) collecting information to build traffic displays inside control centers. The SSR used by GA is called Air Traffic Control Radar Beacon System (ATCRBS) with Modes A and C. The SSR used by the military is called Identification Friend or Foe (IFF) with Modes 1,2,3,4, & C. Civil Mode A is the same as military Mode 3 and it is usually called Mode 3/A. Commercial air carriers have installed Mode S, which allows selective interrogation using each aircraft's unique Mode S identification. Mode S is really a 56 bit airborne digital data link that facilitates air to ground communications and aircraft to aircraft crosstalk. Mode S transponders also broadcast, or *squitter*, their unique ID once per second. All SSR interrogations are transmitted on 1030 MHz and all aircraft responses or reports are transmitted on 1090 MHz.

The second main feature of surveillance is called Airborne Collision Avoidance System (ACAS). ACAS, which is called TCAS (Traffic Alert and Collision Avoidance System) in the FAA, uses the Mode S squitter and SSR responses on 1090 MHz to track the identity of aircraft within line of sight. The ACAS box then interrogates each contact and establishes the range and altitude of all other aircraft in the vicinity. When predetermined altitude, range, and time conditions are met, the ACAS produces an audio traffic alert (TA) for the pilot. ACAS can also produce a vertical resolution advisory (RA) to direct a vertical aircraft maneuver and ensure

altitude separation at the closest point of approach. Additionally, ACAS also has the ability to format the RA within a Mode S message and transmit it to the conflicting aircraft. The range and altitude of the conflicting aircraft is very accurate, but the relative bearing is not accurate enough to allow resolution advisories in the horizontal (come left, come right). All ACAS resolution advisories are in the vertical.

SURVEILLANCE SYSTEMS COMPONENTS

The new CNS environment will rely more heavily on aircraft avionics than does the current air system to insure safe aircraft separation. Because GPS equipped aircraft can compute their own position more accurately than air traffic control radar; aircraft self-reports will soon become standard. For trans-oceanic routes, where flight following radar is not available, aircraft will send position reports addressed to specific air traffic control centers. These self-reports will utilize HFDL or SATCOM data links and will be called Automatic Dependent Surveillance Addressed (ADS-A). Even when primary radar following is available, aircraft will still broadcast periodic GPS based self-reports to allow other aircraft in the vicinity and ground controllers to gain situational awareness. This use of broadcast architecture for aircraft self-reports is called Automatic Dependent Surveillance Broadcast (ADS-B). With ADS-B, all aircraft will be able to have Cockpit Display of Traffic Information (CDTI) functionality. CDTI is the key element needed to develop the required cockpit situational awareness for free flight.

A recently approved upgrade to the Mode S transponder expands the data link message to 112 bits and the new Mode S *extended squitter* broadcasts the aircraft's ID, latitude, longitude, altitude, and velocity vector once per second. With this recent expansion of the Mode S message, a new collision avoidance upgrade called ACAS II or TCAS II change 7, has been introduced. This new functionality captures the information within the Mode S extended squitter (ID, Latitude, Longitude, Altitude, and velocity vector) to build a geodetic traffic display in the cockpit. This CDTI greatly increases situational awareness. The pilot should have sufficient situational awareness to execute traffic deconfliction maneuvers in the horizontal and minimize the number of TAs and RAs produced by ACAS II.

The Mode S extended squitter format is also a possible solution for ADS-B functionality in GA aircraft that don't have ACAS II installed. Without installing the expensive ACAS II avionics equipment with its two antennas and the 1030 MHz interrogator, GA is investigating the functionality of installing a 1090 MHz receiver in the Mode S transponder. With this one box ADS-B solution, GA could listen to the extended squitters of the aircraft around them and build a CDTI in their cockpit. The participation of GA in the Mode S and ADS-B broadcast architecture could greatly increase situational awareness and aviation safety. This effort is strongly supported by civil aviation authorities.

SPECIFIC SURVEILLANCE REQUIREMENTS

To date, neither GA aircraft nor tactical military aircraft have installed either Mode S or ACAS avionics equipment. The transition to CNS surveillance architecture will have a big impact on both GA and the military aviation. EUROCONTROL has announced the implementation dates for Mode S and ACAS II and they present a significant problem for GA and near term military operations. ACAS II will be required for all transport aircraft with more than 30 seats or weight more than 15,000 Kg by January 1, 2000. This ACAS II requirement will be expanded to transport aircraft with more than 19 seats and weight of more than 5,700 Kg by January 1, 2005. The extended squitter Mode S requirement is extended to all aircraft filling IFR flight plans after January 1, 2003 and all VFR flight plans by January 1, 2005. These future requirements have been known for some time but little has been accomplished to address the solution for either GA or tactical military aircraft.

The entire topic of military air surveillance will require a significant analysis of not only the requirements to meet CNS functionality but also the impact of ACAS II and Mode S equipped aircraft on battlespace management. The big military surveillance debate is about to begin. One solution to the military tactical aircraft CNS functionality issue would be to upgrade the AN/APX-100 IFF transponder with Mode S and ADS-B functionality. This solution would mirror the GA plan to capture ADS-B without installing ACAS II. This option deserves a lot of thought and this minor upgrade to the AN/APX-100 could also make it possible to address known deficiencies in Mode 4 and also investigate the utility of an encrypted version of ADS-B to enhance military utility. For the CNS Surveillance issue, a dual use option is available but considerable work will be required to bring it to the front.

CONCLUSION

The 1998 Chairman of the Joint Chiefs of Staff (CJCS) Master Positioning, Navigation, and Timing Plan (CJCSI 6130.01A) states military aircraft must be equipped with suitable instruments and navigation equipment appropriate to the routes to be flown. Navy and Marine Corps tactical aircraft are not required to install avionics equipment that meets FAA Technical Standard Orders (TSO) or ICAO Standards and Recommended Practices (SARPS). However, the minimum performance standards for military aircraft, to be developed by the respective Services, must: conform with civil airspace required navigation performance (RNP) standards, prevent violation of civil air traffic clearances, ensure safe separation of military and civil air traffic, and ensure military aircraft achieve an "Equivalent Level of Safety". Each aircraft's requirements will depend on its mission but within the next few years, most tactical military aircraft will require some communications, navigation, and surveillance (CNS) avionics upgrades to ensure access to sovereign controlled airspace. The specific avionics changes for each aircraft are still unknown but those under consideration include:

- PPS GPS with integrity for primary means of navigation
- Area Navigation (RNAV) functionality
- Required Navigation Performance (RNP-4)
- 8.33 kHz VHF channel spacing
- VHF digital data link functionality

- Mode S
- Collision Avoidance functionality

If the U. S. Military tactical aircraft fail to install the appropriate avionics functionality, loss of access to specific sovereign controlled airspace should be anticipated. The road map to an affordable solution to these issues probably lies in dual use functionality of military avionics.

BIOGRAPHYS

CDR KURT ENGEL, USN

CDR Kurt Engel is a Deputy Program Manager for PMA-209, Air Combat Electronics, a program office of Naval Air Systems Command. He leads the Integrated Program Team for CNS/ATM, which includes Free Flight avionics acquisition planning, and Tactical C4I. Other products supported by his IPT include the TAMMAC moving map, Advanced Mission Computer, ARC-210 Communication System, and APX-100.

CDR Engel has been assigned to Naval Air Systems Command for the last six years in various program management positions. Other programs have included Hunter Shipboard Unmanned Aerial Vehicle, Tactical Control System Command and Control System and Predator UAV.

Previous to his assignment to Naval Air Systems Command, he served as the Production Officer for Naval Aviation Depot Pensacola and as a pilot in various Fleet squadrons and ships. He has a Bachelor of Science in Marine Engineering from the US Merchant Marine Academy and a Masters of Science in Aeronautical Engineering from the Naval Postgraduate School.

MR. GARTH VAN SICKLE

Garth Van Sickle is a Senior Engineer with the DCS Corporation of Alexandria Virginia. He is a graduate of the United States Naval Academy, has a Masters of Science in Aeronautical Engineering from the Naval Postgraduate School and served as a Naval Aviator for over 25 years. He served as a combat A-6 pilot, the operations officer of a nuclear aircraft carrier, and as the Battle Force operations officer for the Arabian Gulf Battle Force during Desert Storm. He had the honor to command three aviation squadrons and is licensed as a Professional Engineer in the Commonwealth of Virginia.

ACRONYMS

ACAS	Airborne Collision Avoidance System
ADS-A	Automatic Dependent Surveillance Addressed
ADS-B	Automatic Dependent Surveillance Broadcast
AEEC	Airlines Electronic Engineering Committee
AIC	Aeronautical Information Circulars
ARINC	Aeronautical Radio Inc.
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automatic Terminal Information Service
BRNAV	Basic Area Navigation
CAA	Civil Aviation Authorities
CDTI	Cockpit Display of Traffic Information
CJCS	Chairman of the Joint Chiefs of Staff
CMU	Communication Management Units
CNS / ATM	Communications, Navigation, Surveillance, Air Traffic Management
CPDLC	Controller to Pilot Data Link Communications
EGI	Embedded GPS INS
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FMS	Flight Management Systems
FTE	Flight Technical Error
GA	General Aviation
GATM	Global Air Traffic Management
GPS	Global Positioning System
HFDL	High Frequency Data Link
ICAO	International Civil Aviation Organization
ID	Identification
IFF	Identification Friend or Foe
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation Systems
JTIDS	Joint Tactical Information Distribution System
LAAS	Local Area Augmentation System
MAGR 2000	Miniature Airborne GPS Receiver
MASPS	Minimum Aviation System Performance Standards
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
NAVWAR	Navigation Warfare
NM	Nautical Miles
NOTAM	Notice to Airman
NPA	Non-Precision Approach

PPS	Precise Positioning Service
PRNAV	Precision Area Navigation
RA	Resolution Advisory
RF	Radio Frequency
RNAV	Area Navigation
RNP	Required Navigation Performance
RTCA	RTCA Inc.
SA	Selective Availability
SARPS	Standards and Recommended Practices
SATCOM	Satellite Communications
SPS	Standard Positioning Service
SSR	Secondary Surveillance Radar
STC	Supplemental Type Certificate
TA	Traffic Alert
TCAS	Traffic Alert and Collision Avoidance System
TDMA	Time Division Multiple Access
TSO	Technical Standard Order
UHF	Ultra High Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency
WAAS	Wide Area Augmentation System

COMMUNICATIONS, NAVIGATION, SURVEILLANCE, AIR TRAFFIC MANAGEMENT (CNS / ATM) with DUAL USE AVIONICS

CDR KURT ENGEL USN

NAVAIRSYSCOM

JUNE 16, 1998

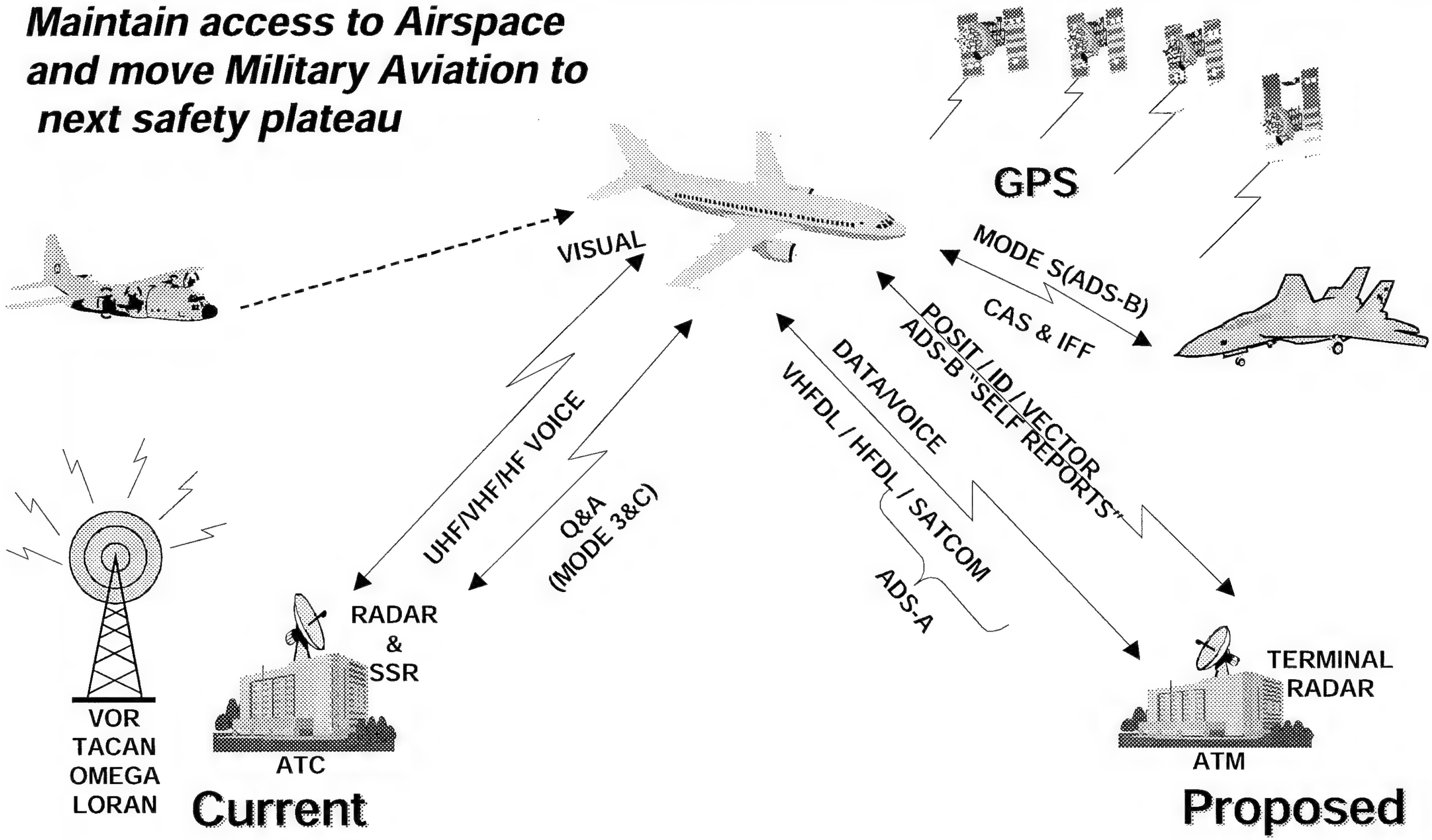
JAWS S3 '98

What are the Drivers?

- Operational Pull
  - Optimum air routing for Air Carriers
  - Improved Safety
  - General Operational Efficiency
  - Cockpit Situational Awareness
- Technology Issues
  - GPS, Digital Communications, Advanced Avionics
  - Finite Frequency Spectrum

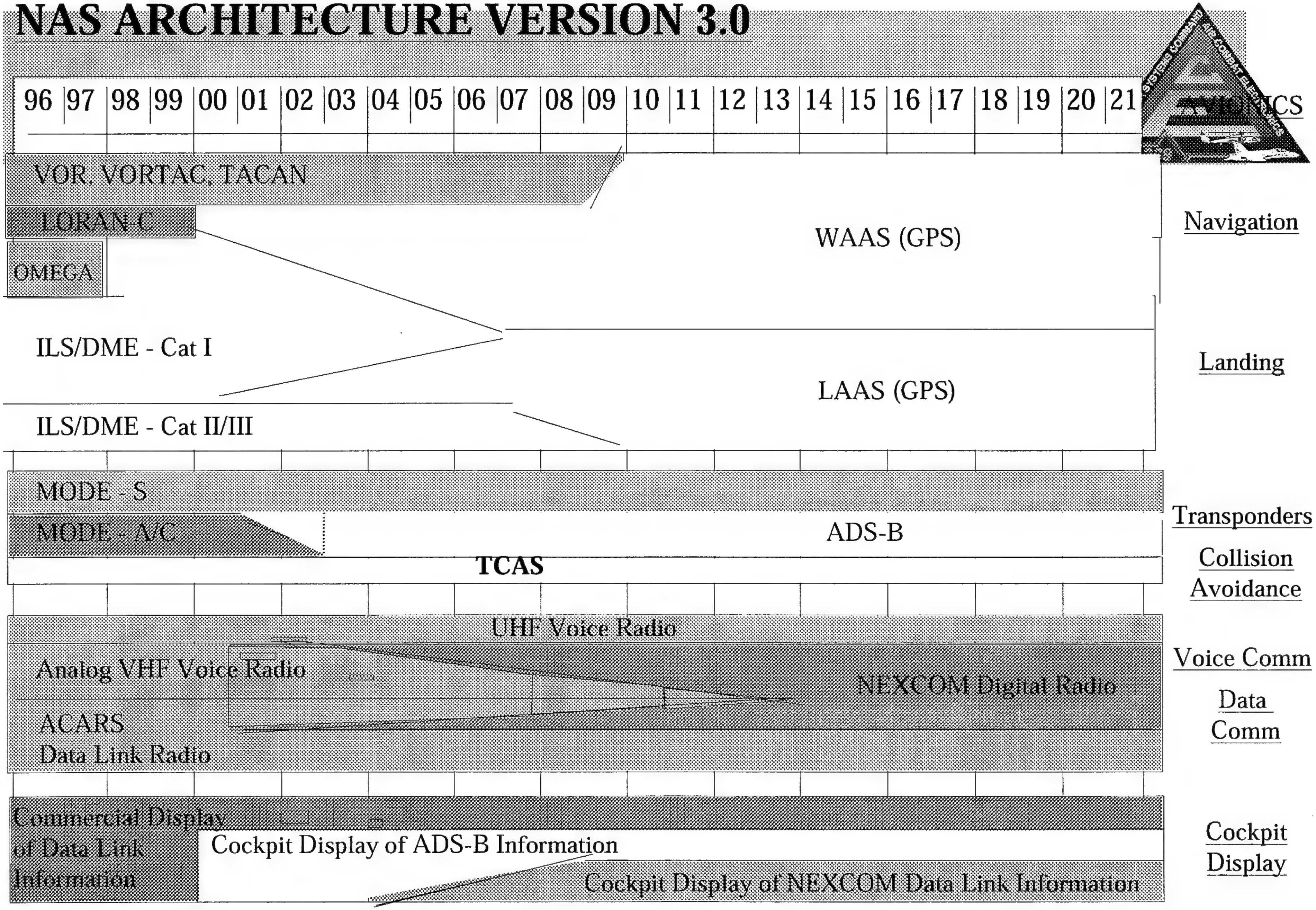
CNS/ATM

Maintain access to Airspace and move Military Aviation to next safety plateau



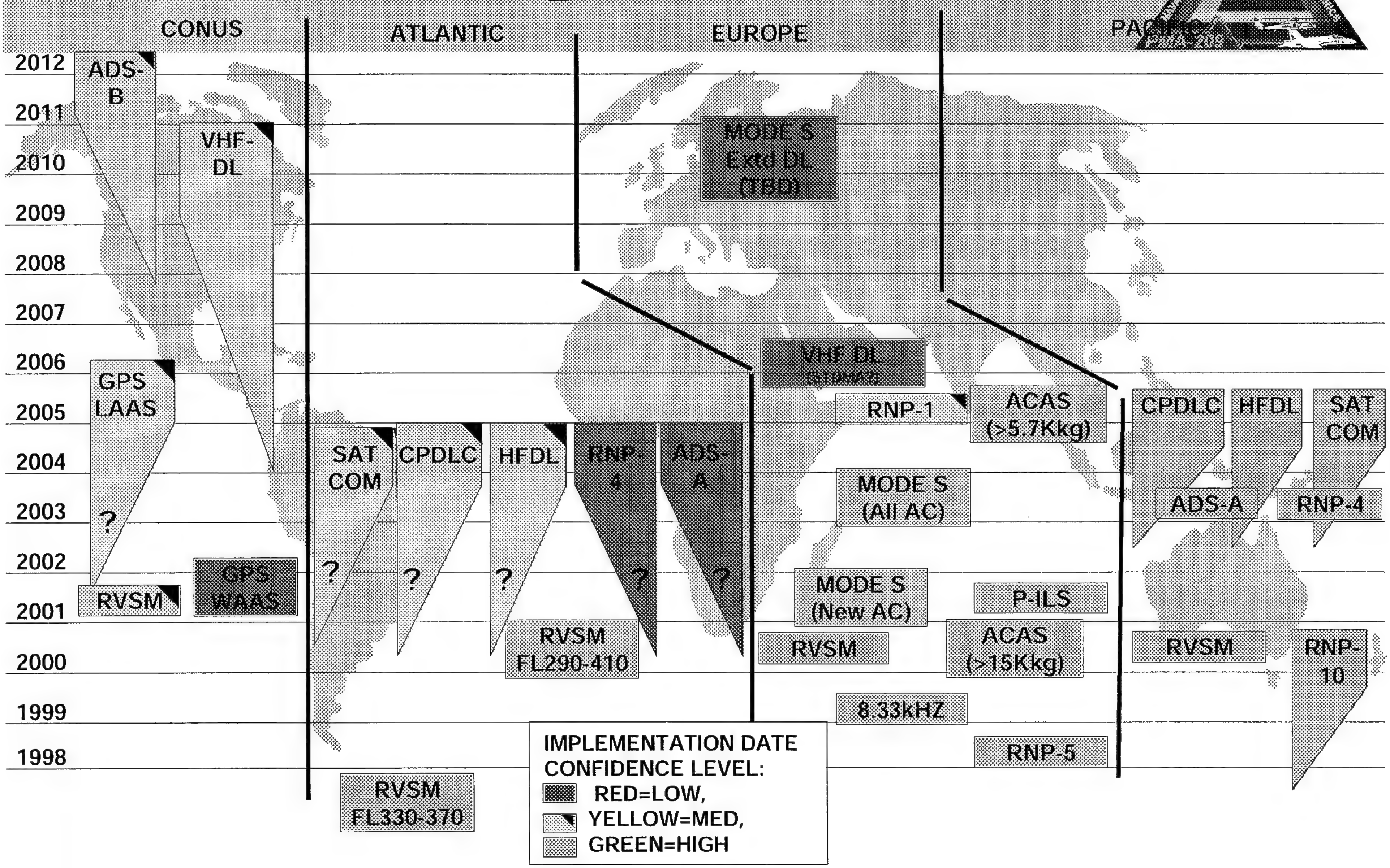
661

NAS ARCHITECTURE VERSION 3.0



PROPOSED AVIONICS TRANSITION

CNS/ATM Requirements



Emerging Requirements

CNS FUNCTIONALITY	IOC	REGION	PHASE ACFT	CRITICAL PATH
RVSM (1K Sep Above FL330)	1997	Atlantic	Phase I	Work around
(1K Sep Above FL290)	2000	Atlantic	Phase I	Work around
BRNNAV (RNP-5)	1998	Europe	Phase I, II & III	TBD
RNP-10	1998	Pacific	Phase I	Will Comply
8.33 kHz VHF Spacing	1999	Europe	Phase I, II & III	ARC-210 with 8.33
P-ILS (Protected ILS)	2001	Europe	All with ILS	COTS
Mode S	**2003**	**Europe**	**Phase I, II & III**	**APX-100 Upgrade (Surv)**
ACAS II	2003	Europe	Phase I & II	COTS
RNP-4(Ocean Air Routes)	2003	Lant & Pac	Phase I	Will Comply
(GPS Flight in NAS)	**2005**	**CONUS**	**Phase I, II & III**	**EGI & MAGR 2000 (Nav)**
VHF Mode 2 DL with CMU	**2003**	**CONUS**	**Phase I, II & III**	**ARC-210 with VDL II (Comm)**
HF Data Link (or SATCOM)	2003	Lant & Pac	Phase I	TBD
VHF Mode 3 TDMA	2005	CONUS	Phase I, II & III	ARC-210 with VDL III

664

Joint Services Plan

"Commercial and Airlift / Tanker"

Close to Full Compliance
(C-9, E-6, C-5, C-17, C-20, C-12, KC-135, etc.)

Commercial Off-the-Shelf

- Lower Cost
- Preserves Civilian Certification (where applicable)
- Compatible with Civil Route and Environment
- Near Term Requirement

"Tactical"

Comply as Required for Access

Upgrades / Replacement to Legacy Avionics

- C4I and RTIC upgrades required

"Low Altitude"

Comply/Waiver as Required for Access
(UH-60, CH-47, OH-58, SH-60, etc.)

Upgrades / Replacement to Legacy Avionics

- Low Altitude Route Operations
- "Dual Use" Avionics Equipment
- JPALS/NAVWAR Considerations
- MIL STD-1553

"Jet"

Comply/Waiver as Required for Access
(F-15, F/A-18, F-22, B-2, RC-12, etc.)

Upgrades / Replacement to Legacy Avionics

- High Alt Route Operations
- Restrictive Tactical Aircraft Environment
- "Dual Use" Avionics Equipment
- JPALS/NAVWAR Considerations
- MIL STD-1553

Survey Draft Results

Phase I

C-9 - $2.1 29 Acft

C-20 - $1.9 7 Acft

E-6 -$5.2 16 + 2

Phase II

C-130 - $902 97 Acft

P-3 - $720 234 Acft

C-2 - $825 38 Acft

C-12 - $559 86 Acft

Phase III

Tacair/Trainers- In Work

CNS-ATM
C-130
(97 Aircraft)
Phase II

CNS-ATM
E-6
(16 Aircraft / 2 Simulators)
Phase I

CNS-ATM
C-20
(7 Aircraft)
Phase I

CNS-ATM
C-9
(29 Aircraft)
Phase I

	Potential Requirement	Req	Inst	Plan	Remarks	A/B/Install	Recur	Non-Recur	Funded	Unfunded
COMM	8.33 kHz	Y	Y		Note 1 (OSIP 9-97)	$ 153	$ 4,430	$ 1,950	$ 6,380	
	VHF Mode II	Y	Y		Note 1					
	VHF Mode III									
	HFDL	Y	N	Y	Note 2 (OSIP 9-97)	$ 326	$ 9,460	$ 2,500	$ 11,960	
	INMAR SATCOM	Y	N	Y	Note 3	$ 166	$ 4,800	$ 3,000		$ 7,800
	CMU	Y	N	Y	Note 4					
	CPDLC	Y	N	Y	Note 4	$ 297	$ 8,600	$ 3,100		$ 11,700
NAV	RNP-10									
	RNP-5 (BRNAV)									
	RNP-4 (GPS/DME)	Y	Y		(OSIP 9-95)	$ 466	$ 13,500	$ 2,700	$ 16,200	
	RNP-4 (GPS/INS)	Y	N	Y	Note 5 (OSIP 9-97)	$ 179	$ 5,200	$ 2,600	$ 7,800	
	RNP-1									
	P-ILS	Y	Y		(OSIP 9-97)	$ 80	$ 2,310	$ 300	$ 2,610	
SURV	ADS-A	Y		Y		$ 269	$ 7,800	$ 2,800	$ 16,940	$ 10,400
	ADS-B									
	RVSM	Y		Y	(OSIP 9-97)	$ 72	$ 2,080	$ 1,700	$ 3,780	
	Mode S	Y	Y		(OSIP 9-97)	$ 31	$ 900	$ 305	$ 1,205	
	TCAS II	Y	Y		(OSIP 9-97)	$ 136	$ 3,940	$ 850	$ 4,790	
								TOTAL	$ 54,725	$ 29,900
								Funded + Unfunded	$ 84,625	
								Cost per ACFT ($K)	$ 2,918	

Notes:
Note 1. 8.33kHz and VHF Mode II Achived with 1 ARC-210 and dual RTA-44D.
Note 2: HFDL achieved with dual HF-900D during phase II.
Note 3: TBD If HFDL or INMARSAT required. Possibly both.
Note 4: CMU and CPDLC costs on same line.
Note 5. RNP-10 & 5 achieved with RNP-4. FMS upgrade to GPS/INS planned for phase III to achieve RNP-4 over water.

6.0.6

CNS/ATM In Tactical Avionics

Communication

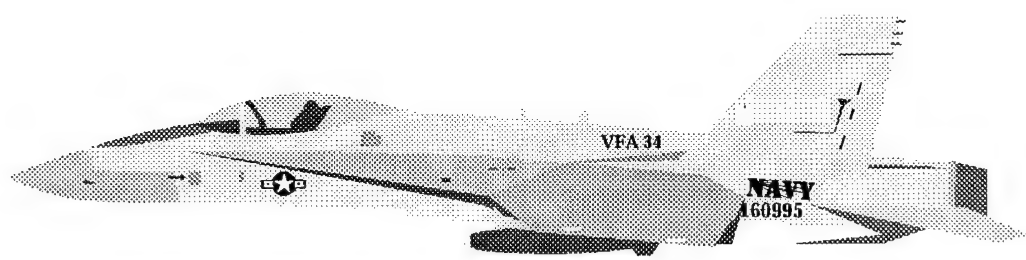
Digital Radios to Handle Reduced Channel Spacing and VHF Data link

ARC - 210

Navigation

GPS Position Accuracy to Meet Required Navigation Performance in Reduced Separation Environment

MAGR 2000 / EGI



Surveillance

Enhanced Situational Awareness, Automatic Position Reporting

APX-100 / MODE S /

ADS-B / Displays

Air Traffic Management

Global Change in Air Traffic Management, Monitoring, Reporting and Ground-Based Infrastructure

DoD Upgrade Required

Challenges

- Define Impacts for Tactical Aircraft Operations
- Leverage existing military capabilities (GPS, ARC-210)
- Enhance wartime mission functionality (Anti-Air Warfare , Combat ID, Real Time Information to the Cockpit)
- Do not increase cockpit workload (human factors)
- Plan and execute lab and field experiments
- React to civil requirements within DoD acquisition cycle

Summary

- All CNS/ATM changes to naval aviation are not known.
- Commercial equipment will be employed where cost effective.
- Non-material solutions where appropriate.
- Upgrades to legacy avionics where required.
- Dual use of equipment to meet both military and civilian requirements.

Backups

Cost Reduction Strategies in Acquiring Aircraft Weapon Systems at "Pax River"

Mr. Phillip F. Zalesak
Naval air Warfare Center Aircraft Division
Patuxwnt River, Maryland
USA
http://www.nawcad.navy.mil

1.0 SUMMARY

The most significant consolidation in the U.S. Department of Defense (DoD) just occurred at the Naval Air Station in Patuxent River, Maryland. This air station is commonly referred to as "Pax River." The U.S. Navy collocated its aircraft program managers, developers, testers, procurement, and logistics personnel at Pax River to achieve greater efficiency and effectiveness in buying aircraft weapon systems. The purpose of this paper is to discuss this consolidation and the tremendous research, development, test and evaluation (RDT&E) capability now resident at this site.

2.0 BACKGROUND

Challenge

With the end of the Cold War and the subsequent dissolution of the Soviet Union, the priority and funding of national defense declined over the past decade. The challenge to the US Navy in the early 1990's was to substantially downsize the work force, reduce the number of support sites, and retain sufficient capability to support the Fleet in anticipation of this new reality.

-Approach

In 1989, the total number of Navy civilians across the U.S. associated with the acquisition and support of naval aviation systems totaled 52,000 people. The Navy's end strengths goal for 1999 is 28,000. This represents a 46 percent reduction in work force. In 1989, the total number of shore station sites was 18 including headquarters and field activities. The Navy's goal for 1999 is to have 8 sites in operation. This represents a 55 percent reduction in shore station sites.

In addition to the downsizing and consolidating more functions at fewer sites, the Navy also reorganized its entire Naval Aviation acquisition corps around a new organizational structure and concept of operations to improve the efficiency of the acquisition process.

Consolidation at Pax River

Since 1943, the Pax River complex has served as the Navy's principal aircraft test and evaluation facility. From 1945 until 1992, the complex was known as the home of the Naval Air Test Center. Due to actions taken as a result of a nationwide Base Realignment and

3.0 PAX RIVER RDT&E CAPABILITY

The NAWCAD Pax River organization represents an enormous consolidation of engineering talent, facilities, and aircraft at one site. The NAWCAD work force is currently 11,400 employees composed

of 1,300 military, 4,100 civil service, and 6,000 contractor personnel. A total of 67 scientific and engineering laboratories are at Pax River as a result of this consolidation. There are also 137 RDT&E aircraft to support the acquisition mission.

Research and Development Capability

North Engineering Center

As part of the BRAC process, Pax River received new facilities to accommodate the influx of the new technical staff and laboratories. The North Engineering Center, a new 255,000 square foot (23,690 sq m) facility, was built principally to accommodate the ASW research and development engineers who moved from Wanninster, Pennsylvania The center is approximately 65% laboratory space and accommodates over 400 personnel. The facility houses hardware integration centers and software production facilities for maritime surveillance aircraft. Within the North Engineering Center is a large acoustic sensors laboratory which is used for the development of new ASW sensors.

The North Engineering Center is located adjacent to the Force Aircraft Test Squadron (FATS) which conducts technical testing of air ASW weapon systems. The aircraft are used by both research and development and test and evaluation personnel. In addition, the operational test and evaluation squadron, VX- 1, is located next to FATS which allows for the timely transition of technology from the research and development laboratory to the operational test and evaluation community due to this collocation.

South Engineering Center

The South Engineering Center, a new 450,000 square foot (41,807 sq m) facility, was built principally to accommodate the influx of air vehicle, aircrew systems, and avionics technologists from Warrninster, Pennsylvania and NAVAIR headquarters. The facility houses over 800 engineers and scientists.

Within the South Engineering Center are numerous air vehicle, aircrew systems, and avionics labs. One of these is the Horizontal Accelerator, a certified facility used for operational testing and evaluation of various systems in crash environments. The heart of the facility is an accelerator capable of providing controllable and repeatable time-mirrored crash pulses simulating the conditions which occur during crash on land or in water. The facility has supported tests and evaluation of rigid and energy-attenuating seats, ejection seats, clothing assemblies, restraints, and body-mounted equipment.

Materials Laboratory

The Robert N. Becker Laboratory is adjacent to the South Engineering Center. This laboratory is home to the aerospace materials division at Pax
_78,000 square-foot (7,246 sq m) building.

Test and Evaluation C3pabilities

Air Station

The Pax River Complex is located 60 miles (97 km) south of Washington, D.C., and 90 air miles (145 km) from the Fleet in Norfolk, Virginia (Figure 5). The complex is composed of a 7,000 acre (28.3 sq

km) Naval Air Station at Patuxent River, Maryland, and an 850 acre (3.4 sq km) Webster Field annex located 10 miles (16 km) away. The main all-weather sea level airfield at Pax River has three heavy capacity runways:
6,400 ft; 9,700 ft; and 11,800 ft (1,951 m, 2,957 m, and 3,597 m) long. Eleven hangars provide over 1.2 million square feet of space (111,483 sq m).

Air Space

The Pax River Complex is located beneath a restricted air space controlled by Naval Air Station Air Operations. The restricted air space is approximately 60 miles (96 km) by 30 miles (48 km) wide. This restricted air space and the Warning Areas immediately off the East Coast provide 50,000 square miles (129,500 sq km) of air space in which to conduct flight test operations.

Naval Test Wing Atlantic

Currently, Pax River is the busiest flight test center in the world with over 20,000 hours being flown by the Naval Test Wing Atlantic, an organizational arm of the Test and Evaluation Group(Figure 3). Flight operations include activities performed by the Strike, Rotary Wing,
and Force aircraft test squadrons and the U.S. Naval Test Pilot School. Strike platforms include the F/A-i 8, F-i 4, EA6B, T- 45, and UAV's; surveillance aircraft such as the E-2C, P-3, and S-3; and rotary wing aircraft such as the V-22, SH-6013, UH-60, and CH-53 helicopters.

Test Article Preparation

The Test Article Preparation group provides aircraft irurumentation and aircraft modification services. A complete metal shop and composite shop capability allow rapid prototyping of aircraft modifications which enables proof-of-concept testing aboard RDT&E aircraft. Recent activities have included the integration of missiles aboard maritime patrol aircraft and the incorporation of guns aboard Navy helicopters.

Atlantic Ranges and Facilities

The Atlantic Ranges and Facilities Department provides both flight and ground test facilities necessary for the comprehensive evaluation of aircraft weapon systems. Significant ground and flight test facilities include the following:

Air Combat En~ironment Test and Evaluation Facility (ACETEF): This facility is a fully integrated ground test facility allowing full-spectrum test and evaluation of aircraft and aircraft systems in a secure and controlled engineering environment. The facility uses state-of-the-art simulation and stimulation techniques to provide test scenarios that will reproduce actual combat conditions. Aircraft systems are
Aircraft Test and Evaluation Facility (ATEF): The ATEF provides the capability to ground test installed aircraft propulsion, mechanical, electrical, and pneumatic subsystems in a controlled environment, during static and engine operating conditions. This facility is an enclosed, acoustically designed building which can operate 24 hours per day regardless of noise or weather restrictions. The facility can be made "light tight" and provides a suitable environment for the evaluation of night vision devices.

Dynamic In-Flight Radar Cross Section Measurements

The Radar Cross Section ~CS) measurement facility conducts dynamic in-flight RCS, jammer-to-signal ratio, chaff measurements relative to aircraft, helicopters, UAV's, towed targets, and decoys. The integrated facilities provide telemetry, tracking data, range control, airborne instrumentation, and RCS data acquisition, all in a centralized workstation allowing analysis and display of the in-flight dynamic RCS measurements in real time. Data products include RCS amplitude versus aspect, Doppler power spectrum, downrange profiles, and Inverse Synthetic Aperture Radar imagery measurements.

Electronic Warfare Flight Test Facility ~WFTF)

The EWFTFis comprised of a wide variety of highly sophisticated equipment that supports the test and evaluation community. These discrete systems (made up of transmitters, receivers, tracking and slaved antenna pedestals, fixed antennas, emitter control circuitry, and computers) are configured to generate a wide variety of radar and communication radio frequency signatures in support of aircraft electronic warfare (EW) avionics test measurements. The EW facility also develops, maintains, and operates special purpose data acquisition, processing and display systems. The combination of these systems and the RF signature generators is used to support a wide variety of in-flight EW integration test measurements.

Automatic Carrier Landing Systems (ACLS) Facility

The ACLS Facility has cradle-to-grave responsibility for air traffic control and landing systems used onboard carriers, amphibious assault ships, and Marine Corps expeditionary airfields. This facility provides the ability to correlate airborne data, ground systems data, and independent tracking data for flight analysis. The facility assures that these landings systems provide safe and reliable approach and landing guidance to all shipboard and expeditionary aircraft in all weather and sea state conditions. The facility supports the development and testing of current and future systems, new and modified hardware and software, and the development of both ground and airborne control systems.

Carrier Suitability Facilities

Carrier suitability facilities include a steam catapult and arrestment engine on one of the runways. Use of these facilities is necessary to determine if new or modified equipment installed on

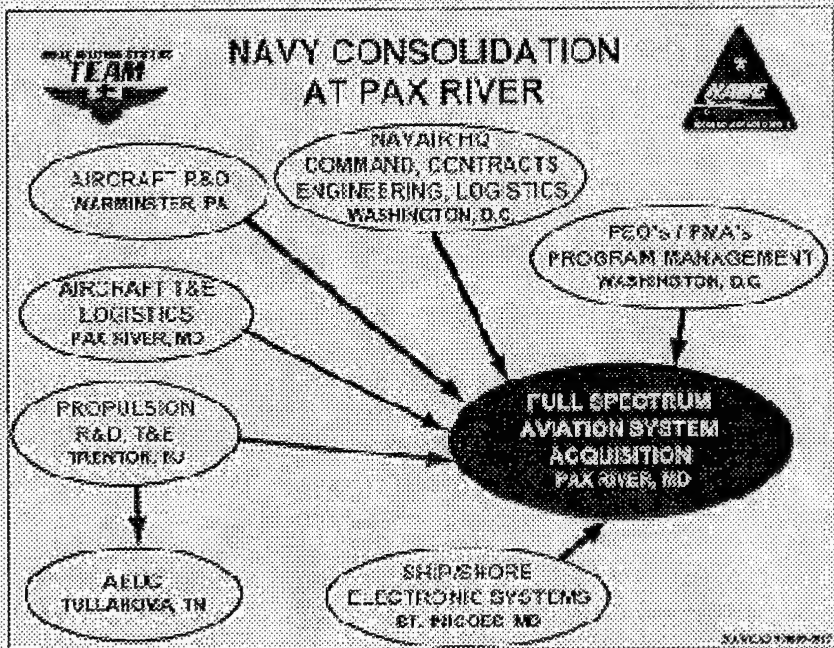


Figure 1

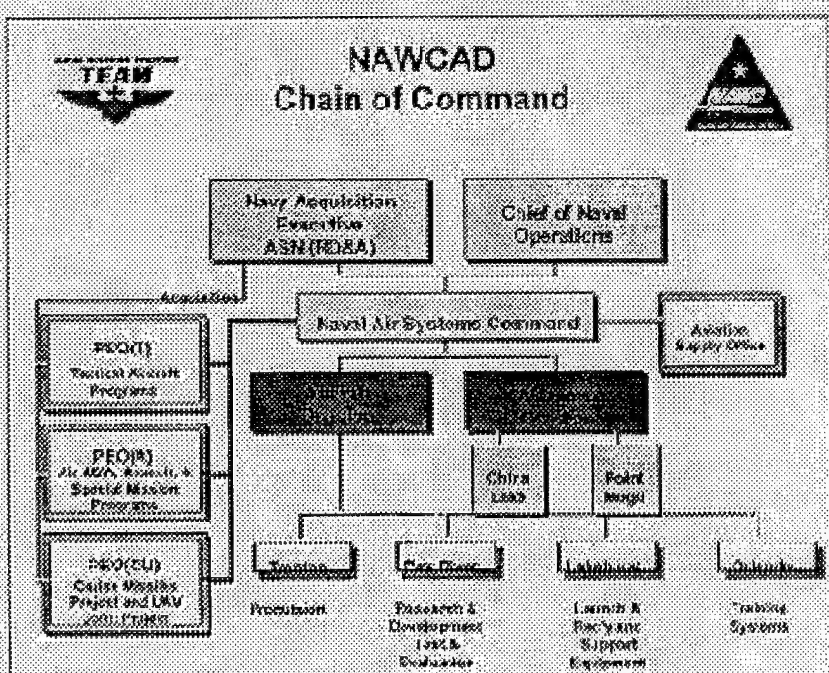


Figure 2

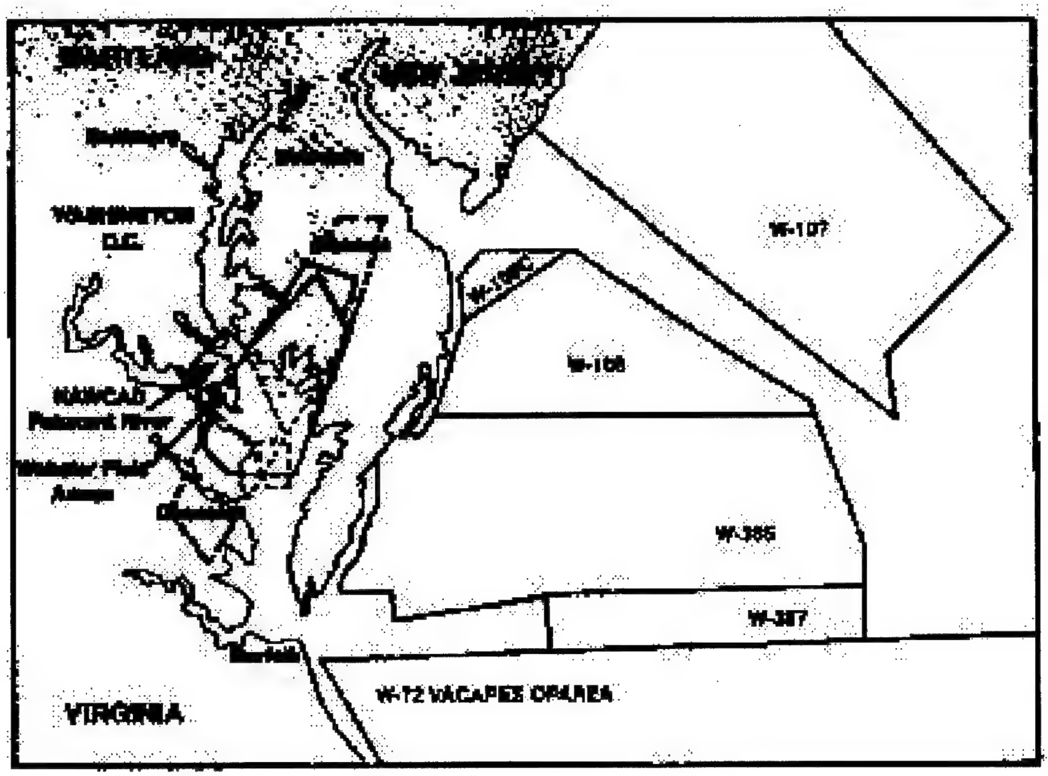
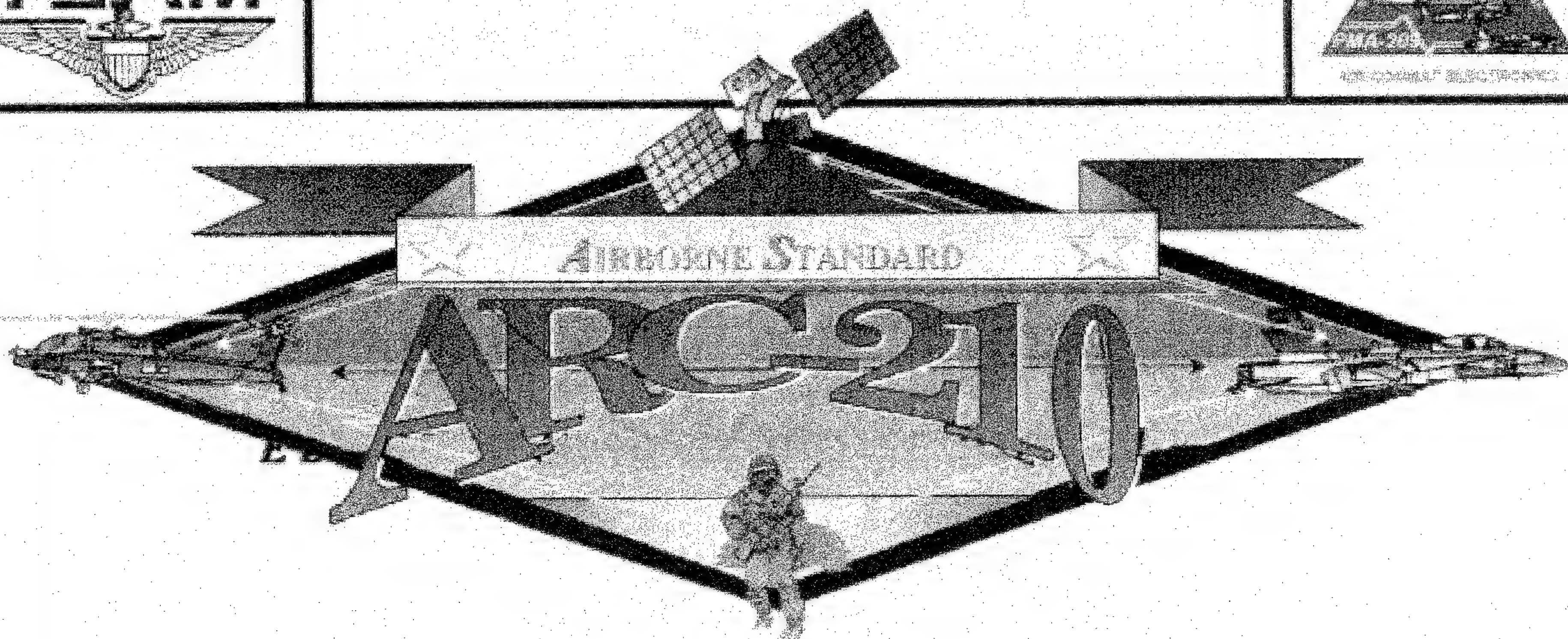

W-107
W-108
W-387
W-72 VACAPES OPAREA
VIRGINIA
NAWCAD
Patuxent River

Figure 5

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO



By

Kenneth W. Lee, PMA-209D

Communications Integrated Product Team Leader, AN/ARC-210(V)

16 June 98

Joint Avionics, Weapons, and Systems Support, Software and Simulation

Program Origination

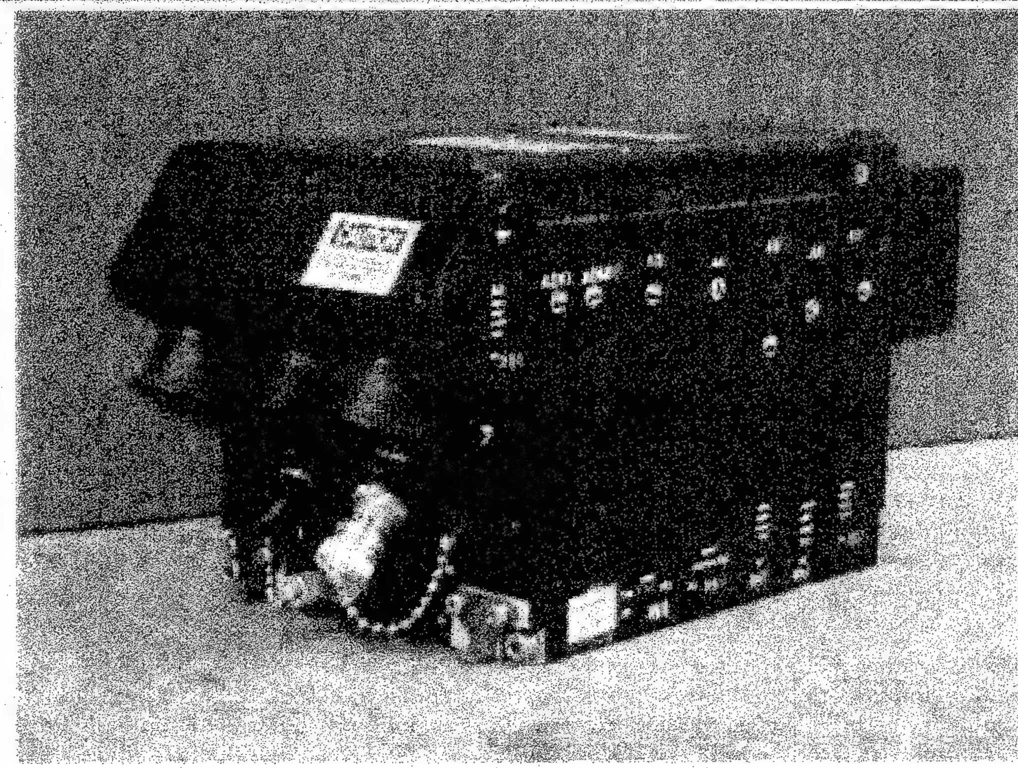
- F/A-18 was pursuing ***unique*** solution to satisfying CAS message exchange
  - Eliminating obsolescence/readiness issues with AIC and simultaneously embed CAS messaging exchange with FO/FAC
    - In advance of ORD
      - December 1995
  - ORD approved 15 May 1998
- PMA-209 ARC-210 IPT
  - Developed program relying on Rockwell-Collins experience with ARC-210 and CAS messaging exchange with FO/FAC
  - Satisfy all Navy aviation with one time non-recurring investment for form, fit replacement to predecessor system
    - maintain PMA-265 thresholds for cost/schedule and functionality
    - provide additional functionality (e.g., DAMA SATCOM) for all other platforms to mechanize

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

RT-1794(C)/ARC

It's here,... NOW!

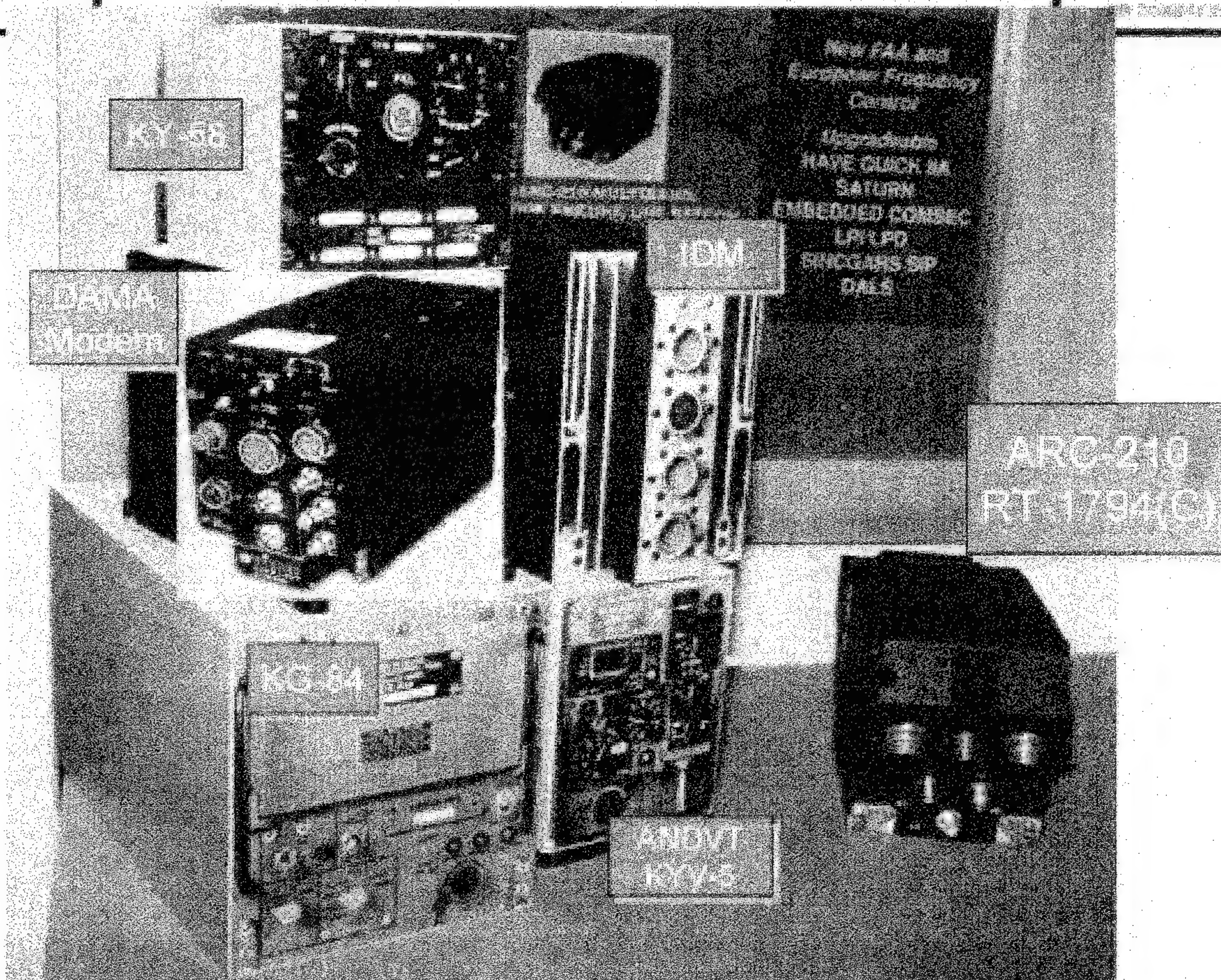


- NSA Endorsed
- JITC Certification
  - MIL-STD-188-181 complete
  - MIL-STD-188-182 due to complete 15 June 1998
  - MIL-STD-188-183 due to complete 30 June 1998
- Bench, EMI, and Environmental Qualifications to complete 30 June 1998
- Production representative units delivered
- Production deliveries commence August 1998 for C-5

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Why We Developed It

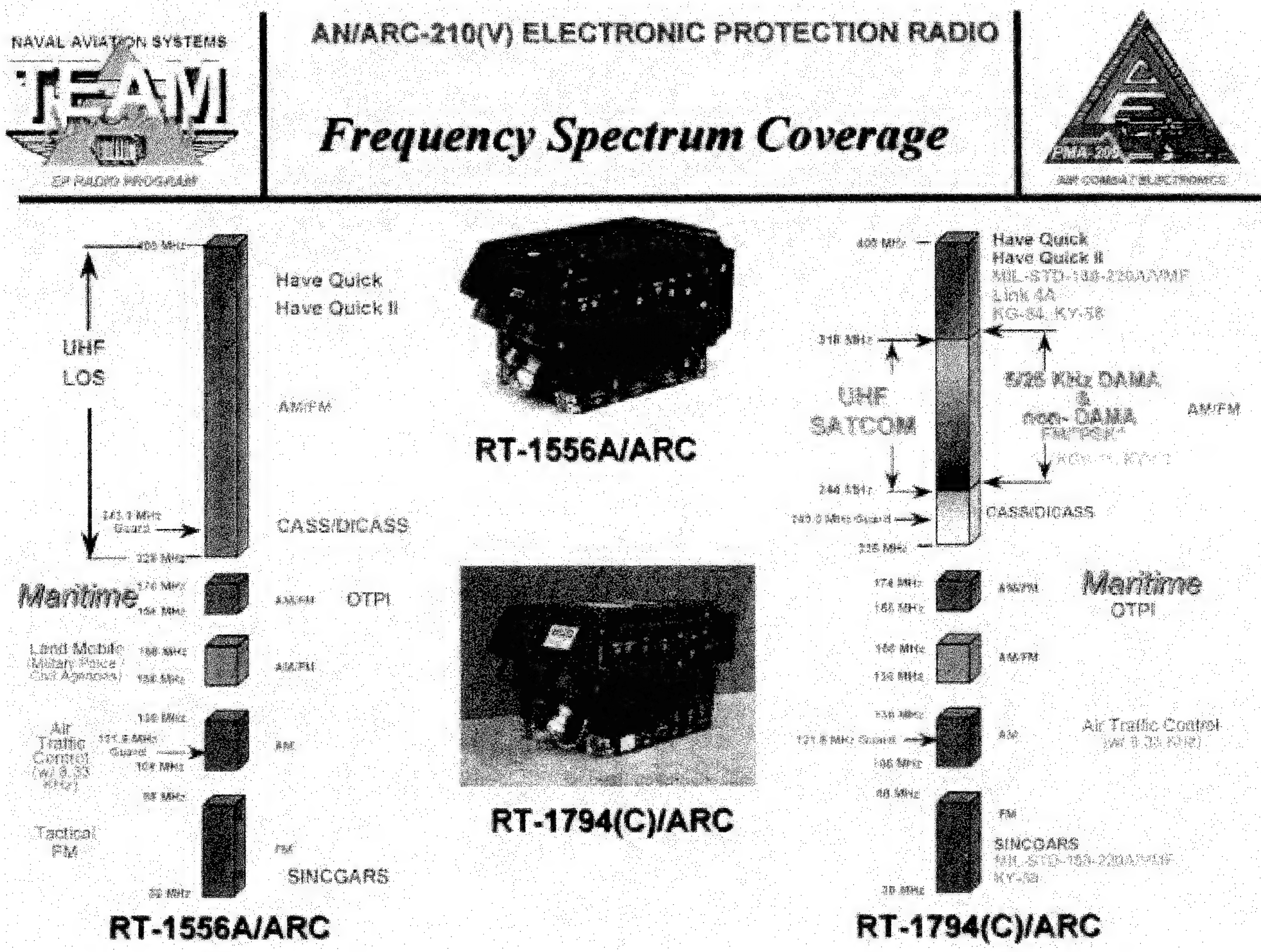


NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

RT-1794(C)/ARC
Current Functional Capabilities

- **RETAINS ALL PRODUCTION BASELINE FUNCTIONALITY**
  - » SINGLE CHANNEL VHF/UHF, AM/FM
  - » SINCGARS
  - » HAVEQUICK AND HAVEQUICK II
- **EMBEDS COMSEC**
  - » KY-58, KYV-5, KGV-11, KG-84
- **EMBEDS DAMA SATCOM**
  - » MIL-STD-188-181/182/183
- **EMBEDS CAS DIGITAL MESSAGE TRANSFER**
  - » MIL-STD-188-220A PROTOCOL
    - VARIABLE MESSAGE FORMAT (VMF)
- **EMBEDS LINK 4A/ACLS FUNCTIONALITY**
- **ADDS EUROPEAN 8.33 KHz CHANNEL SPACING**
- **ADDS ADVANCED MEMORY LOADER VERIFIER (AMLV) CAPABILITY**


NAVAL AVIATION SYSTEMS
TEAM
EP RADIO PROGRAM
AN/ARC-210(V) ELECTRONIC PROTECTION RADIO
Frequency Spectrum Coverage
AIR COMBAT ELECTRONICS
UHF
LOS
Have Quick
Have Quick II
AM/FM
CASS/DICASS
Maritime
OTPI
Land Mobile
Air
Traffic
Control
Tactical
FM
SINCGARS
RT-1556A/ARC
RT-1794(C)/ARC
Have Quick
Have Quick II
Link 4A
UHF
SATCOM
5/25 KHz DAMA
&
non- DAMA
AM/FM
CASS/DICASS
Maritime
OTPI
AM/FM
Air Traffic Control
SINCGARS
RT-1556A/ARC
RT-1794(C)/ARC

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Common Solution

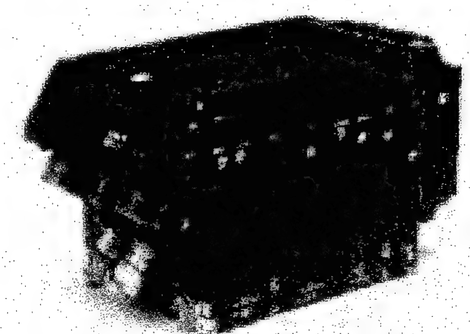
UHF
- ARC-116
- ARC-109
- ARC-159
- ARC-164
- ARC-182
- ARC-187

VHF Maritime
- URC-80

VHF Land Mobile

VHF ATC
- ARC-115
- ARC-182
- ARC-186
- ARC-222

VHF Tactical-CAS
- ARC-54
- ARC-114
- ARC-182
- ARC-186
- ARC-201
- ARC-222

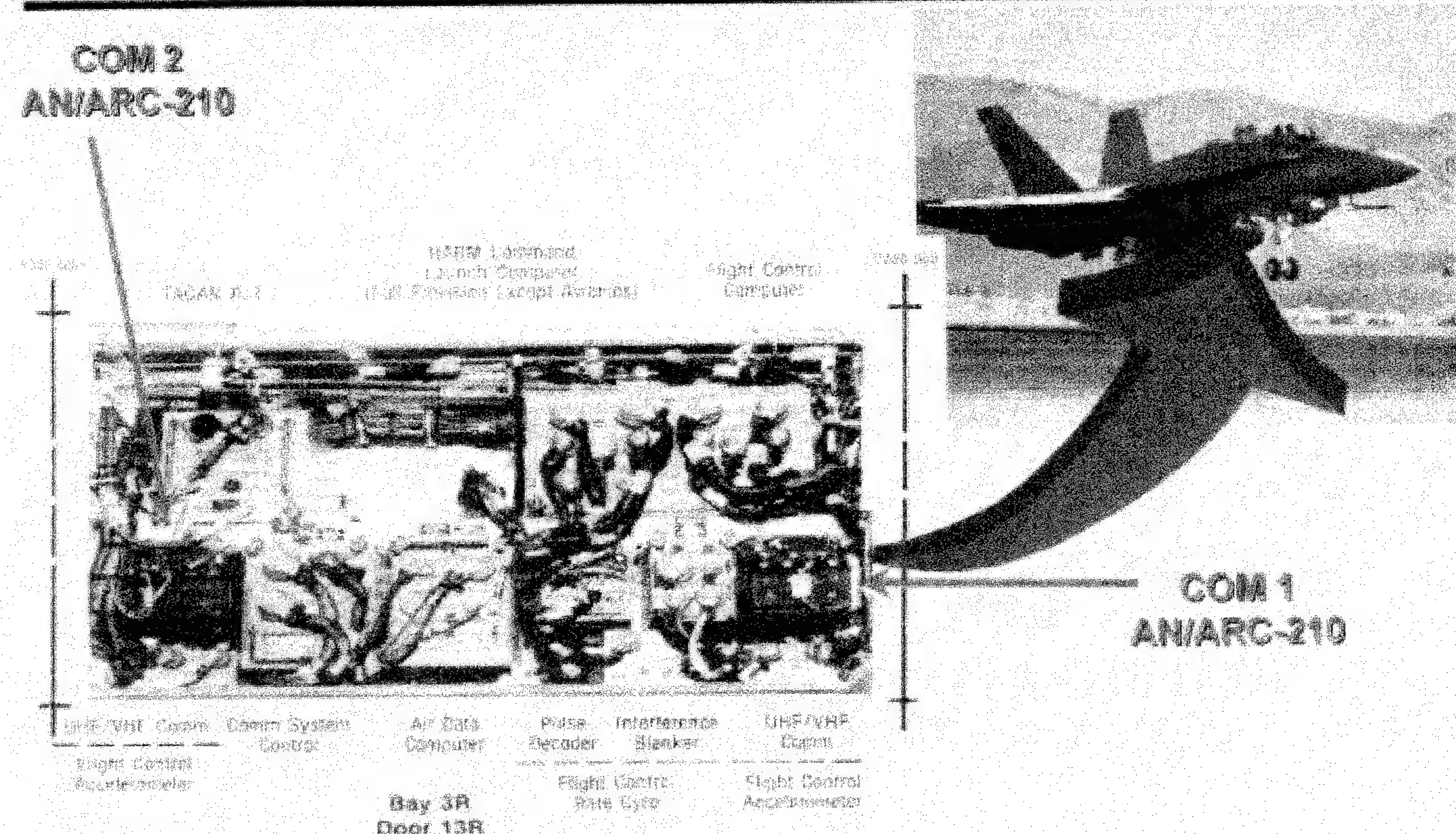


RT-1794(C)/ARC
14 lbs

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

F/A-18C/D
Avionics Bay 3R Equipment



NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Program Summary

AIR COMBAT ELECTRONICS

PLANNED INVENTORY

5331	UNITS - NAVY/MARINE CORPS
452	UNITS - AIR FORCE
51	UNITS - ARMY
304	UNITS - OTHER (FMS, FAA, ETC...)
6138	

PLANNED USERS

F/A-18C/D/E/F, C-2A, C/M/HV-22, UH-1N, UH-1Y, C-130J, AH-1W, AH-1Z, HH-60H, SH-60R, CH-60, C-5, CVN-76, LPD-17, HH-60J, SH-60F, C-29 (FAA), C/DC-9, K/LC-130H/F/R B-52H, SH-2G (FMS), MATCALS, RC-135, UAV, C-17, LCAC, AV-8, CH-46, EA-6B, CH-53, ASC-15B, U-2,160[th] Task Force

POTENTIAL USERS

F/A-18A, RAH-66, E-6A, JLENS, WC-130, UAV TIER III(-), MARAD(T-AVB), 101st AVN BRIGADE, EC-135, DDG-89 (AF), AAAV, JSTARS(E-8C), EC-130, KC-135, E-4B, DDG-85-88

STAGE

PRODUCTION,INTEGRATION, AND DEVELOPMENT

CONTRACTOR

ROCKWELL COLLINS, INC.

SCOPE

ACAT III

RT-1556/ARC | RT-1747C/ARC | RT-1794/C)/ARC

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Incremental Cost Effective Improvements

AIR COMBAT ELECTRONICS

RT-1556A

- VOLUME: 274.4 IN³
- WEIGHT: 12.2 LBS
- POWER: 23 WATTS
- COST: $33K PER UNIT

CAPABILITES
- ECCM/LOS (VOICE & DATA)
- COMBINED UHF/VHF (30-400MHz)
- DEDICATED GUARD
- COMSEC COMPATIBLE
- SINCGARS
- HAVEQUICK I/II
- 8.33 kHz CHANNEL SPACING

RT-1747C

- VOLUME: 316.1 IN³
- WEIGHT: 12.5 LBS
- POWER: 125 WATTS*
- COST: $37K PER UNIT

CAPABILITES
- ECCM/BLOS (VOICE & DATA)
- COMBINED UHF/VHF (30-400MHz)
- DEDICATED GUARD
- COMSEC COMPATIBLE
- SINCGARS
- HAVEQUICK I/II
- 8.33 kHz CHANNEL SPACING
- FEDERATED 5 & 25kHz UHF SATCOM/DAMA

RT-1794(C)

- VOLUME: 232.4 IN³
- WEIGHT: 14 LBS
- POWER: 125 WATTS
- COST: $42K PER UNIT

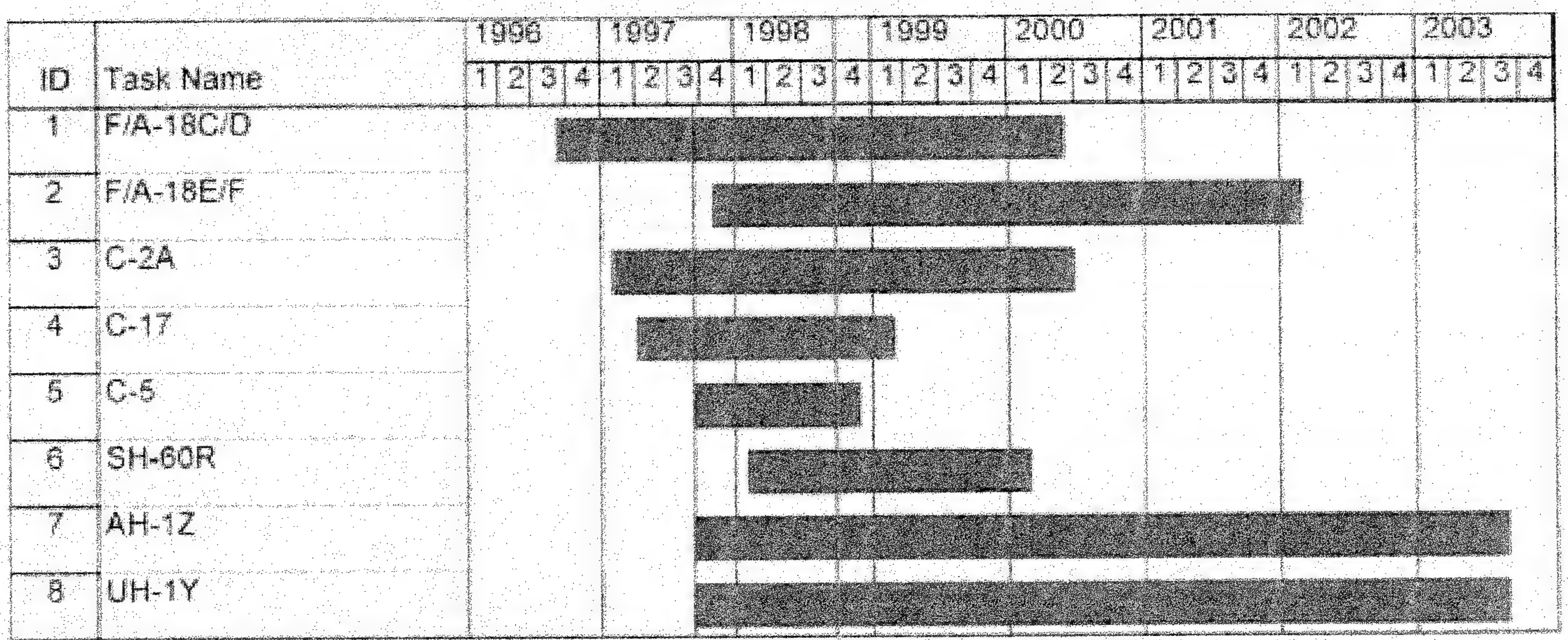
CAPABILITES
- ECCM/BLOS (VOICE & DATA)
- COMBINED UHF/VHF (30-400MHz)
- DEDICATED GUARD
- SINCGARS
- HAVEQUICK I/II
- 8.33 kHz CHANNEL SPACING
- MIL-STD-188-220A & VMF
- EMBEDDED 5 & 25kHz UHF SATCOM/DAMA
- EMBEDDED LINK 4A/ACLS
- EMBEDDED COMSEC
- MLVS

* With High Power Amplifier

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

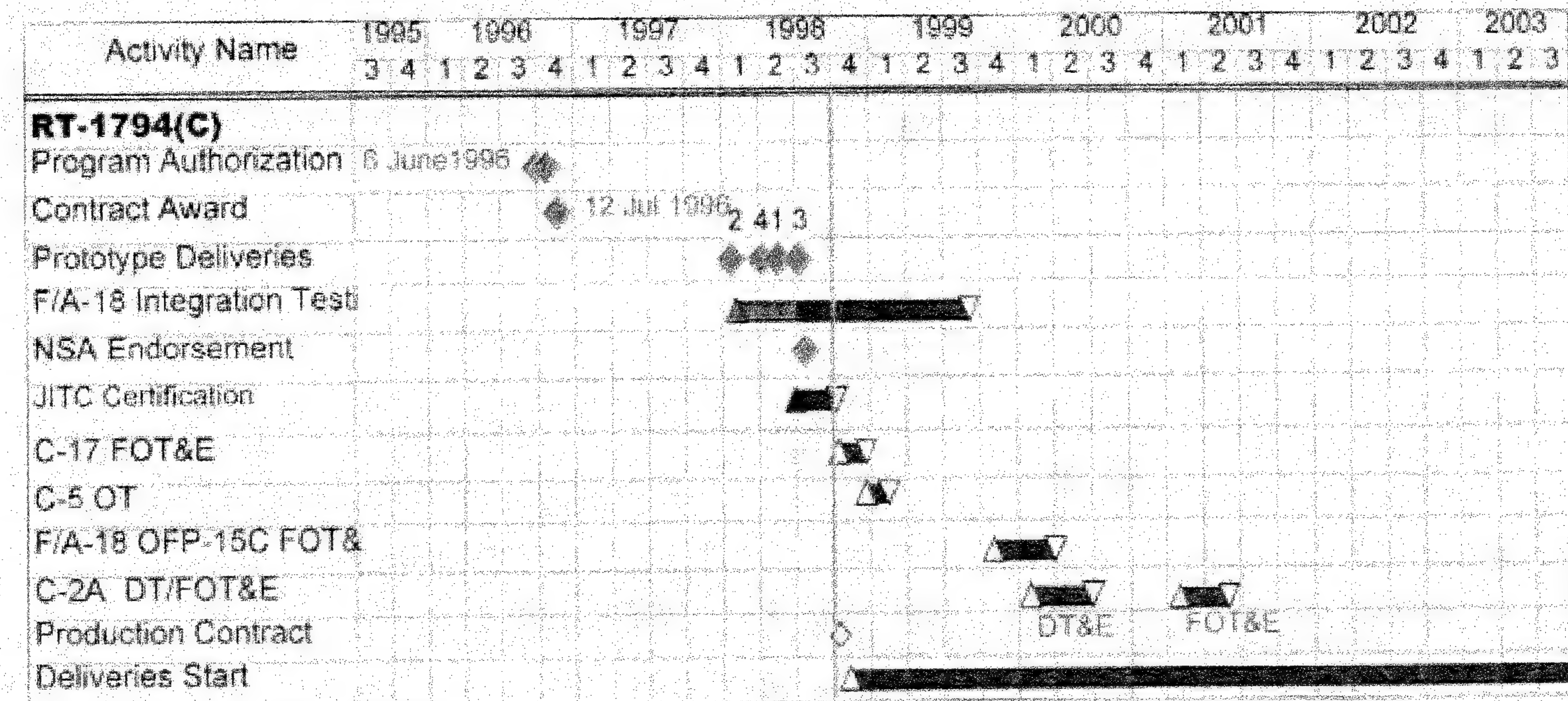
Current Integration Activity



NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Program Schedule



NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

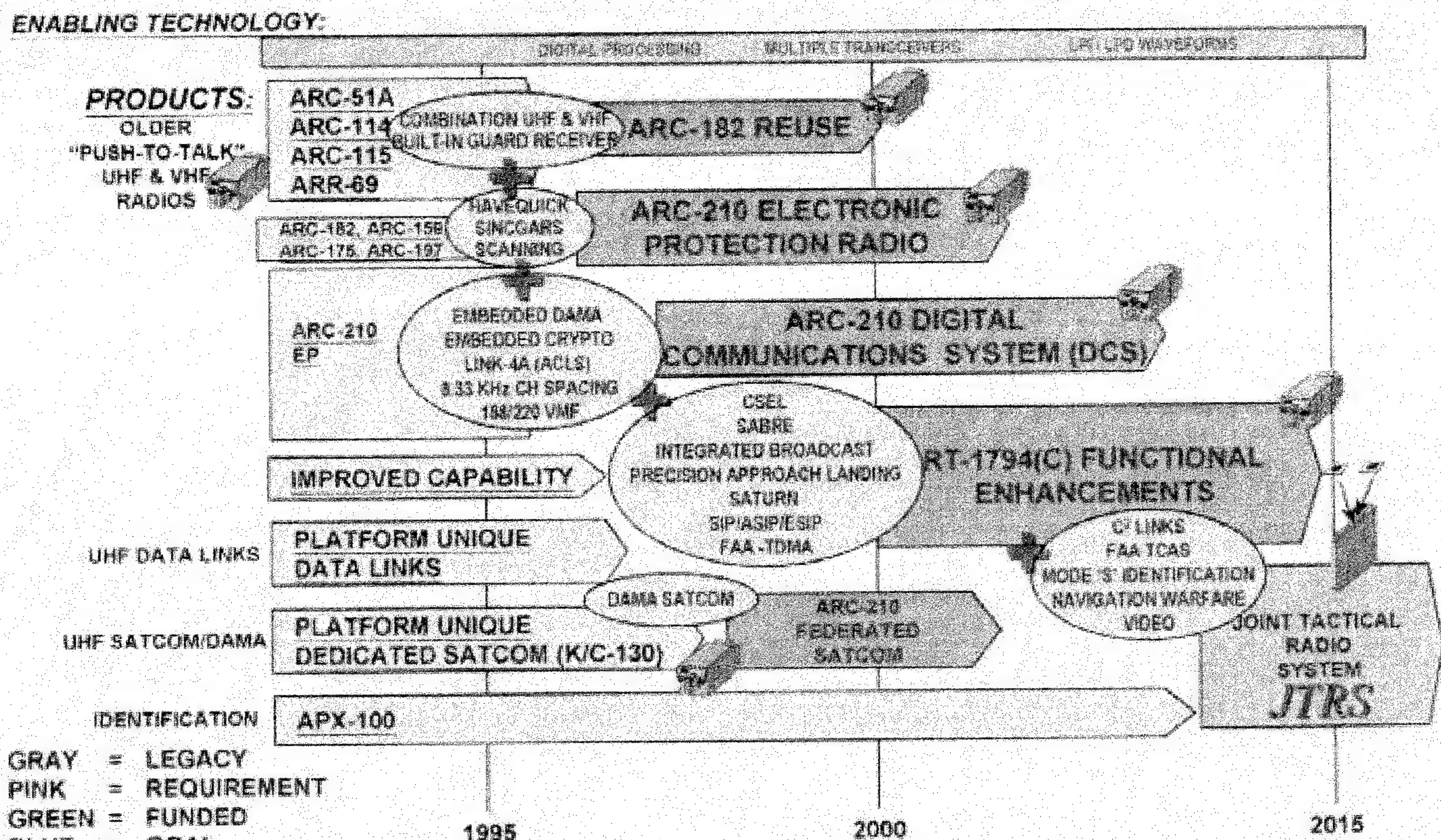
USN and JTRS

- " It is anticipated that the AN/ARC-210(V) will continue to meet the needs of Naval Aviation through 2010 and as a result of a highly innovative and successful acquisition strategy, this radio will not require a planned obsolescence replacement prior to 2015."
- "The AN/ARC-210(V) fully meets our current VHF/UHF requirements for LOS and OTH communications and has more than sufficient growth capability to economically accommodate emerging requirements such as GATM, TDMA, CSEL, and SIP ... "
- "It is N88's position to remain with the AN/ARC-210(V) as the Navy standard airborne radio through at least FY2010. This position is based upon N88's significant investment to date, the maturity of the AN/ARC-210(V) product, its substantial capabilities and an economical growth path which meets a majority of the current and emerging requirements proposed for JTR."

\- RADM Dennis V. McGinn
Dir, Air Warfare Division

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO
Communications Road Map



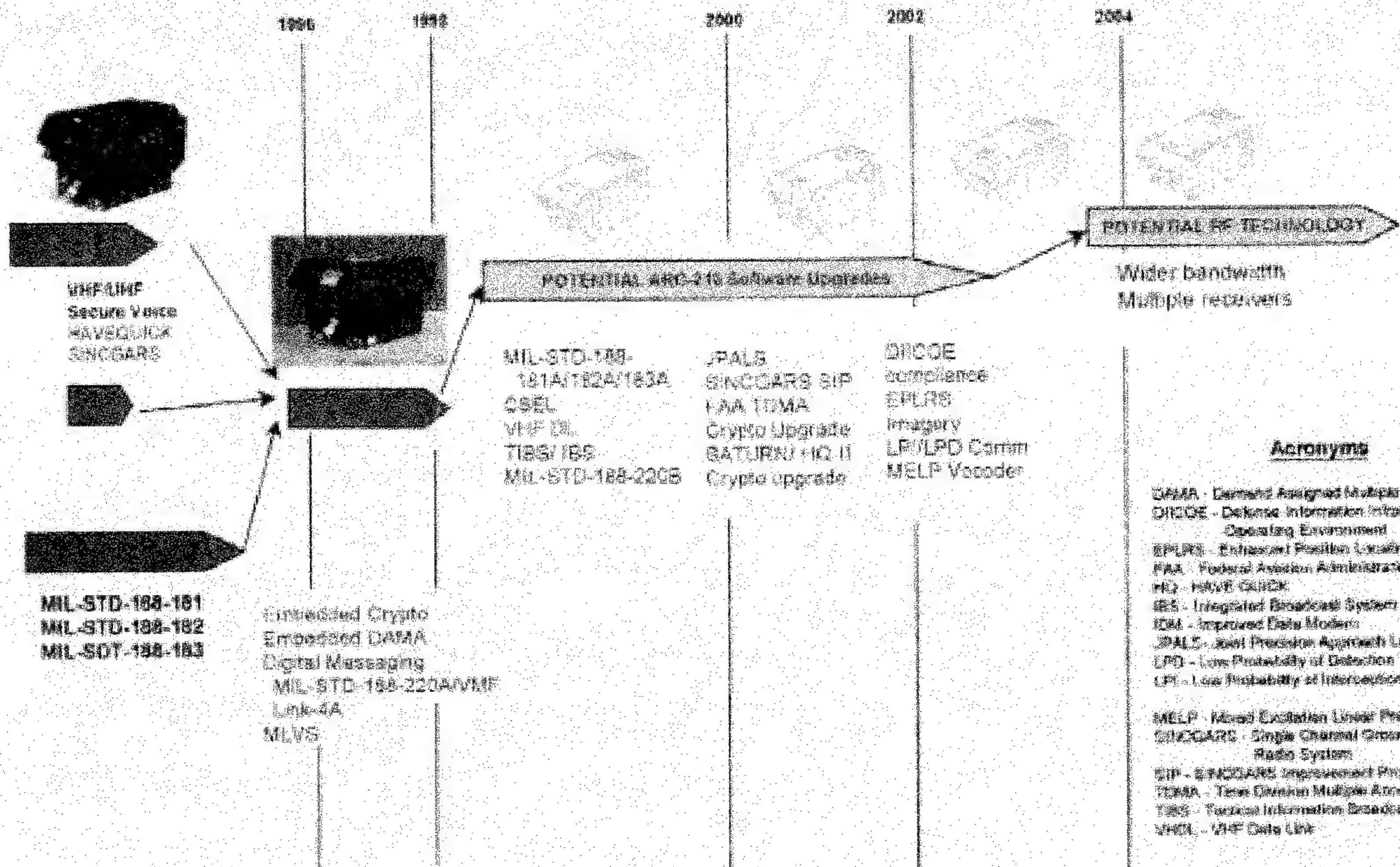
GRAY = LEGACY
PINK = REQUIREMENT
GREEN = FUNDED
BLUE = GOAL

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Technology Roadmap

AIR COMBAT ELECTRONICS



Acronyms

DAMA - Demand Assigned Multiple Access
DIICOE - Defense Information Infrastructure Common Operating Environment
EPLRS - Enhanced Position Locating Reporting System
FAA - Federal Aviation Administration
HQ - HAVE QUICK
IBS - Integrated Broadcast System
IDM - Improved Data Modem
JPALS - Joint Precision Approach Landing System
LPD - Low Probability of Detection
LPI - Low Probability of Interception

MELP - Mixed Excitation Linear Predicted
SINCGARS - Single Channel Ground and Airborne Radio System
SIP - SINCGARS Improvement Program
TDMA - Time Division Multiple Access
TIBS - Tactical Information Broadcast System
VHDL - VHF Data Link

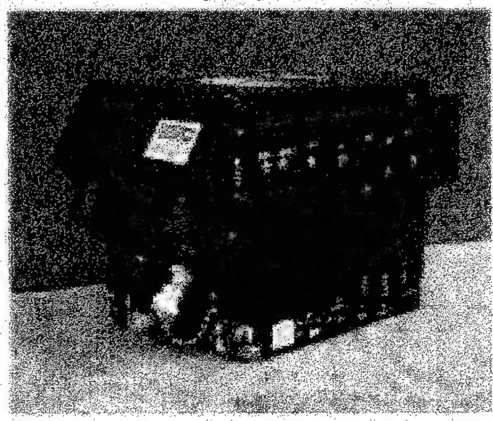
6

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Requirement Satisfaction

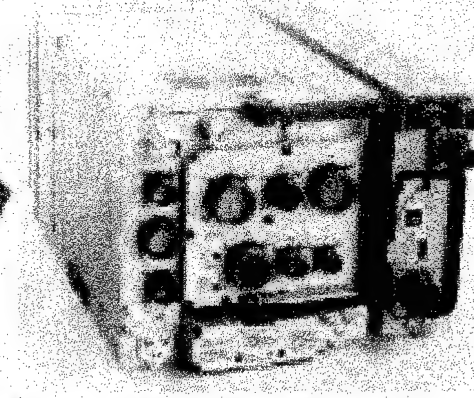
RT-1794(C)/ARC



- VHF/UHF
  - Single channel Voice and Data
  - 8.33 KHz Channel Spacing
  - SINCGARS EP
  - HAVEQUICK & HAVEQUICK II EP
  - Link 4a/ACLS
- MIL-STD-188-220A protocol
  - Variable Message Format (VMF)
- DAMA SATCOM
  - MIL-STD188-181/182/183
- Embedded Crypto
  - KY-58, KG-84, KYV-5, KGV-11
- MLVS

Plus

MIDS



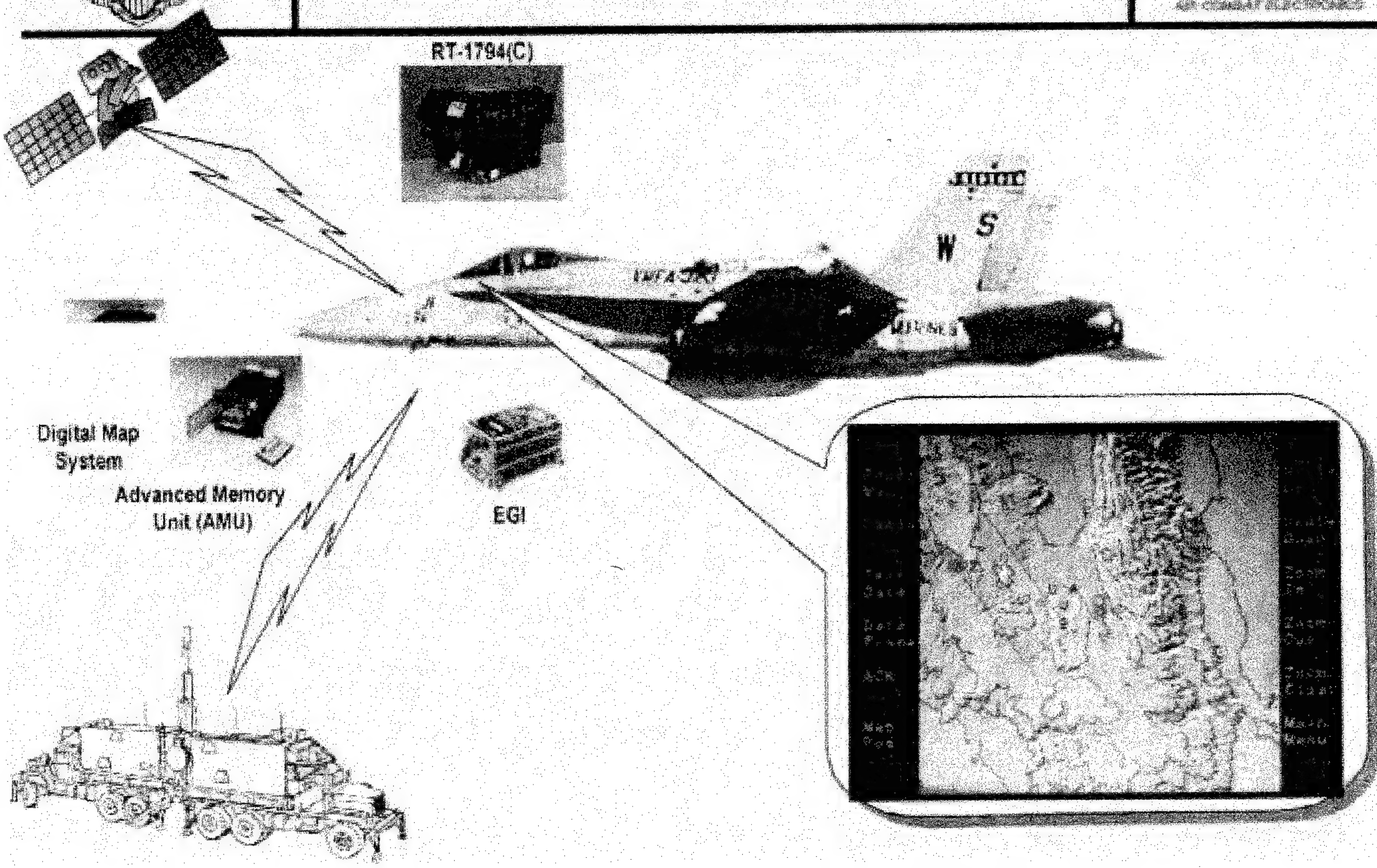
- Upper UHF (Lx Band)
- Link 16 (TADIL J) Fighter Data Link (FDL)
- Situational Awareness
  - At a glance portrayal of targets, threats and friendly forces
    - Jam resistant TDMA voice/data wide area communications (LOS + relay)
- Joint Interoperability
  - Supports Link 16, IJMS (NATO Link 11) and VMF
- Information superiority
  - Surveillance data
  - EW data
  - Mission tasking
  - Weapons assignment
  - Control data

Equals

Naval Aviation Communication Requirement

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Real Time In the Cockpit



NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

JOINT TACTICAL RADIO ORD

00	01	02	03	04	05	06	07	08

JTR FUNCTIONS FROM ORD

00	01	02	03	04
VHF-AM	UHF LOS	LINK 11	ATC HF DL	Cellular
VHF-ATC	HF ALE	LINK 4-A	ATC VHF DL	MELP
SINCGARS	SIP/ASIP	EPLRS	TIBS/CIBS	SATURN
UHF DAMA		GPS-Gov	Link 16	INMARSAT
HQ I/II		PCS		
		WB Digital -WF		VMF/LINK 16 Translation

Potential Applications

- •E-2C
- •JSF
- •CSA
- •MMA
- •SHIPBOARD

- Functions in ARC-210 1794C /Near-Term Implementation
- JTR functions not in 1794C

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

Technology Evolution

Baseline ARC-210 LOS EP RADIO

Weight:	12.2 lbs
Volume:	274.4 in³
Power Out:	23 watts
MTBF:	500 hrs
Cost:	$44K

ARC-210 Federated SATCOM

Weight:	13.3 lbs
Volume:	294 in³
Power Out:	~23 watts
Pred. MTBF:	728 hrs
Cost:	$47K

ARC-210 DCS with 8.33 KHz European ATC, Embedded VMF, L-4A, COMSEC & SATCOM/DAMA

Weight:	14.0 lbs
Volume:	274.4 in³
Power Out:	~23 watts
Pred. MTBF:	1500 hrs
Cost:	$40K

ARC-210 DCS with SIP, CSEL, INTEL, SATURN/HQ IIa, TDMA ATC

Weight:	TBD lbs
Volume:	TBD in³
Pred. MTBF:	>1500 hrs
Cost:	TBD

RT-1556A/ARC

and

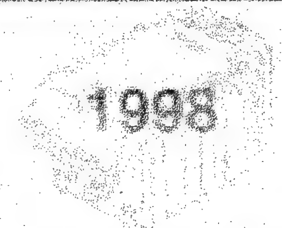
TSEC/KY-58

RT-1747C/ARC

and

TSEC/KY-58
Weight: 4.87 lbs
Volume: 128.55 in³

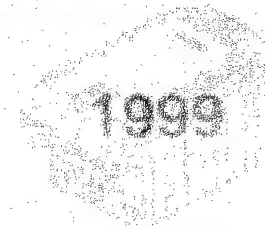
CV-3591/KYV 5 (ANDVT)



RT-1794(C)/ARC

and

AM-7526/ARC (HPA)
Weight: 13.5 lbs



RT-XXXX/ARC

* REQUIRED ONLY FOR PLATFORMS EXPLOITING SATCOM

65

Integration Investment

- RT-1794(C)/ARC Non-recurring $16.0M

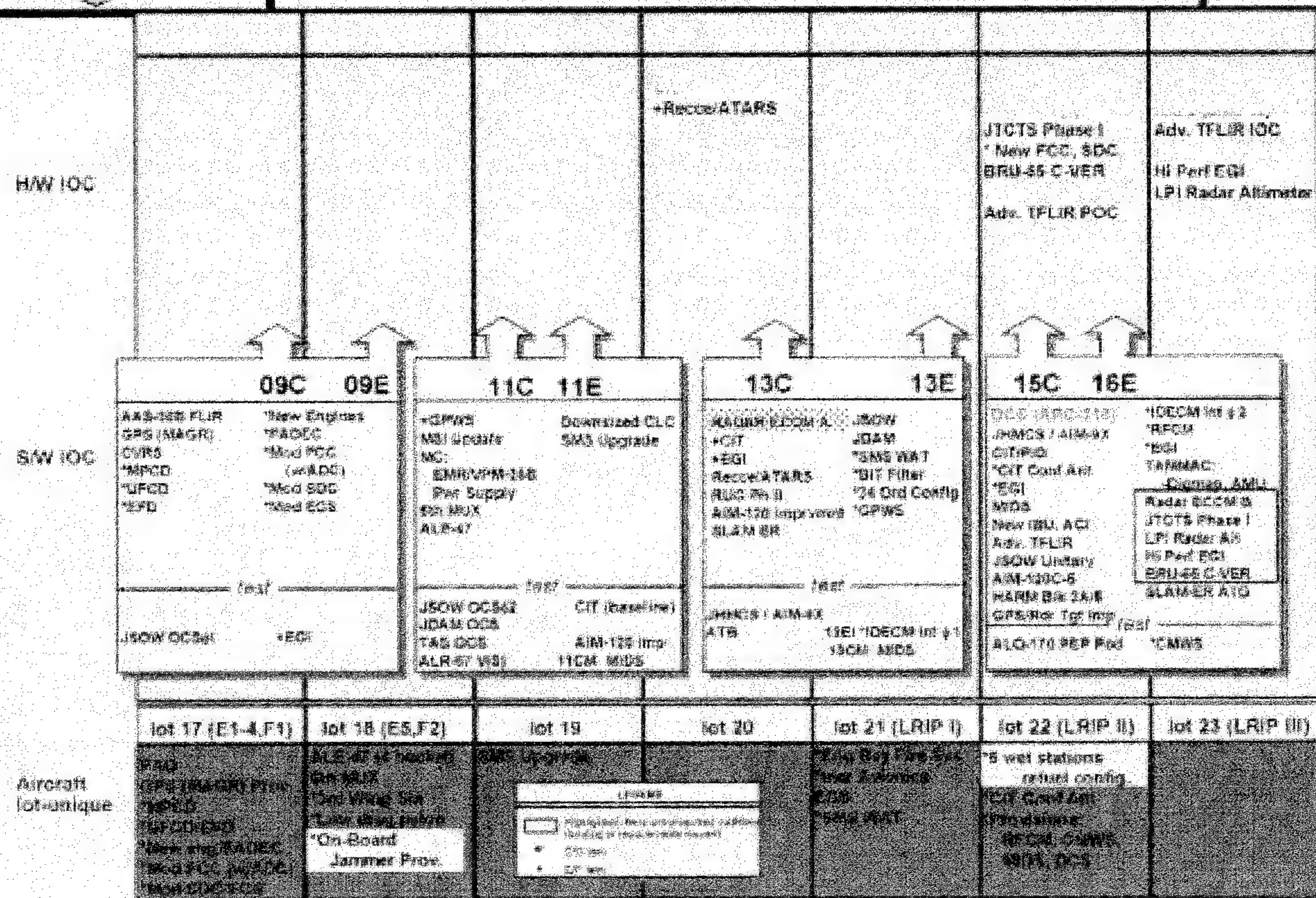
- FA-18C/D
  - Non-recurring $12.0M
  - Recurring (A-Kit) $20K
- Others
  - F/A-18E/F
  - C-2A
  - C-17
  - C-5
  - SH-60R
  - AH-1Z
  - UH-1Y

SH-60R, AH-1Z, UH-1Y: Recent competitive awards

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

F/A-18 Systems Development Roadmap (FY95-01)



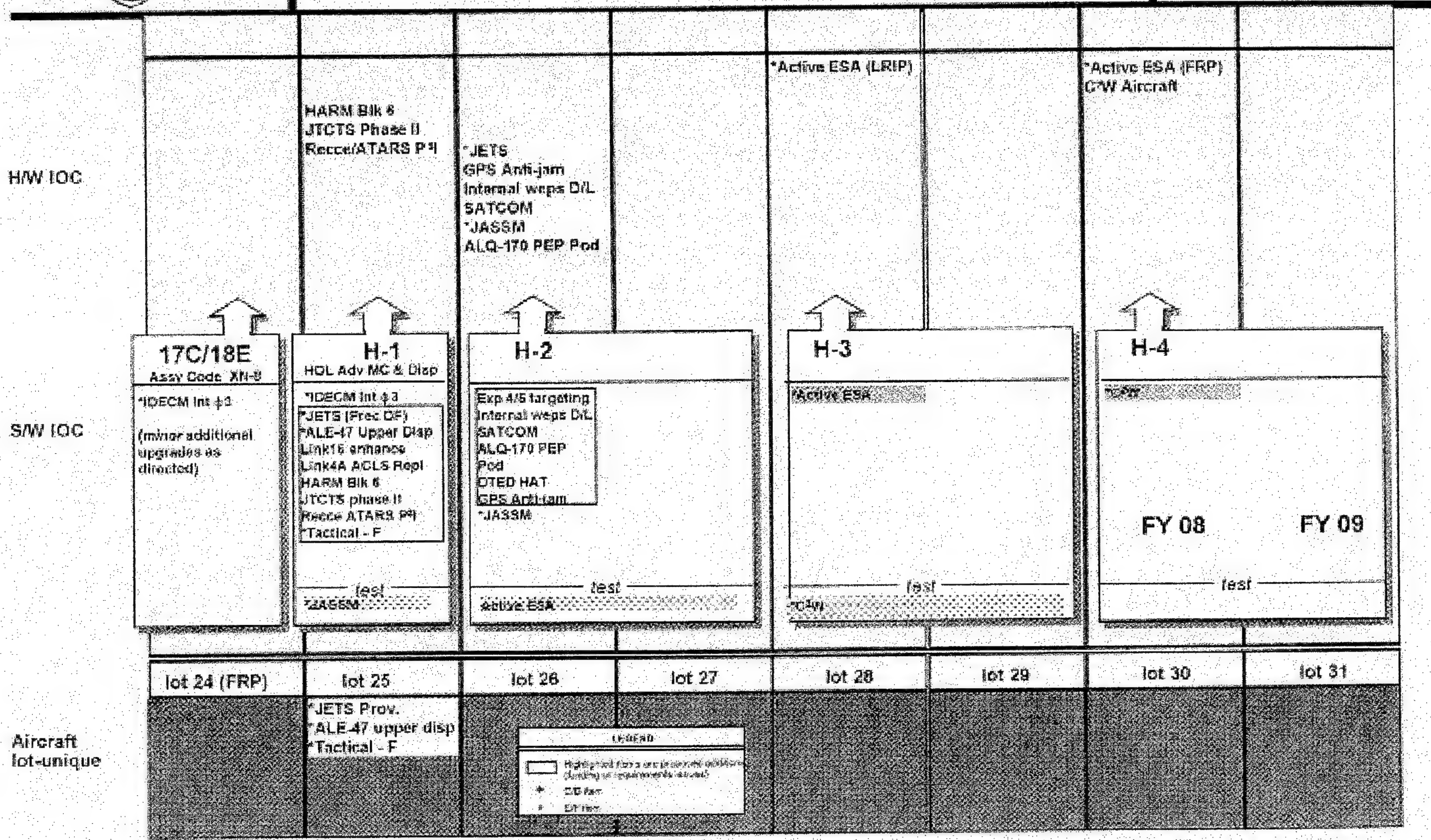
AIR COMBAT ELECTRONICS

NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

F/A-18 Systems Development Roadmap (FY02-09)

PMA-209 AIR COMBAT ELECTRONICS



NAVAL AVIATION SYSTEMS TEAM

AN/ARC-210(V) ELECTRONIC PROTECTION RADIO

User Requirements

AIR COMBAT ELECTRONICS

Customer							FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07
AH-1W(U)	APN-1	USN	41	1794	2 2, RT-1794	82	0	0	0	0	0	0	10	24	48	82
C-2A	APN-5	USN	36	1794	2 2, RT-1794	72	0	2	2	2	34	34	0	0	0	74
C-5	C-5	USAF	255	1794	1 1, RT-1794	255	0	255	0	0	0	0	0	0	0	255
CH-60	APN-1	USN	134	1794	2 2, RT-1794	268	0	48	36	36	36	36	36	36	4	268
CV-22	APN-1	USAF	38	1794	4 4, RT-1794	152	0	0	0	28	24	28	28	28	16	152
CVN-76, LPD-1	SWAR	USN		1794	3 3, RT-1794	3	0	3								3
CVN-76, LPD-1	SWAR	USN	1	1794	12 12, RT-1794	12	0	12	0	0	0	0	0	0	0	12
DDG-85-88	SWAR	USN		1794	2 2, RT-1794	8	0	8								8
DDG-85-88	SWAR	USN	4	1794	16 16, RT-1794	64	0	64	0	0	0	0	0	0	0	64
DDG-89 AF	SWAR	USN		1794	2 2, RT-1794											0
F/A-18 C/D (U)	APN-5	USN		1794	1 1, RT-1794	435	0	0	24	66	66	82	82	82	32	434
F/A-18 E/F (U)	APN-1	USN		1794	1 1, RT-1794	174	0	0	24	36	36	36	36	36	36	240
H-2	FMS	OTH	11	1794	2 2, RT-1794	22	0	2	4	20						26
HH-60H	APN-5	USN	40	1794	2 2, RT-1794	80	0	0	0	40	40	0	0	0	0	80
HH-60J	APN-5	USN	42	1794	2 2, T-1794	84	0	0	0	42	42	0	0	0	0	84
KC-130J	APN-1	USN	51	1794	1 1, RT-1794	51	0	5								5
LPD-17, CVN-7	SWAR	USN		1794	9 9, RT-1794	9	0	9								9
MATCALS	OPN	USN	82	1794	5 5, RT-1794(C	435	0		70	100	110	50	80	25		435
MV-22	APN-1	USN	190	1794	2 2, RT-1794	360				CFE	CFE	CFE	60	60	60	180
SH60 (CV)	APN-1	USN	60	1794	2 2, RT-1794	120	0							24	24	48
SH-60B	SH-60B	USN		1794	2 2, RT-1794											0
SH-60R	APN-1	USN	188	1794	2 2, RT-1794	376	0	38	30	38	42	40	40	40	40	308
UH-1N(U)	APN-1	USN	41	1794	3 3, RT-1794	123	0					15	36	36	36	123
WC-130J	AF	USAF		1794	2 2, RT-1794			10								10
RT-1794 Expected Totals						**3205**	**0**	**456**	**190**	**408**	**430**	**321**	**408**	**391**	**296**	**2900**

A Laboratory Development and Networking Concept for Naval Aviation

William H. Schibler
Naval Air Systems Command,
Avionics Department
Patuxent River, MD

Rodney S. Katz
Aircraft Technologies Group
Pacific Sierra Research Corporation
Arlington, VA

Kathy Seals
Naval Air Warfare Center, Weapons Division
Avionics Department
China Lake, CA

Abstract

This paper presents a concept for laboratory utilization and networking in support of avionics systems development and integration for Naval Aviation. The Naval development centers for air systems have a number of separate laboratory facilities that deal with the many facets of avionics systems in Navy airborne platforms. The laboratories associated in developing and implementing this concept are those located at the Naval Air Warfare Centers (NAWCs) at Patuxent River MD, China Lake CA and Point Mugu CA. The purpose of exploring and then implementing this concept is to ensure that the Navy makes maximum use of the laboratory resources available, and through networking, provides a capability for multiple center participation in shared program developments.

The effort underway is embodied in two elements: Modular Avionics Integration Laboratory (MAIL) and Modular Avionics Integration Network (MAIN). The MAIL element is concerned with the identification and networking together, laboratory resources within the confines of a single development center. The MAIN concept is a networking approach for linking the three centers so that inter-center participation can be achieved for broad scope systems development and integration programs. Taken together, the MAIN and MAIL represent a forward step towards implementing a consistent systems engineering based process for avionics systems evaluation, development and integration for the Navy.

1.0 Introduction

In the current era of downsizing, the tendency is to examine every resource for its value to the enterprise. Resources of the Naval Air Systems Command (NAVAIR) "Naval Aviation Systems Team" are continually being assessed and evaluated to determine whether value added (often measured as return on investment) merits their retention. Over

the years, the Navy has acquired numerous laboratory elements widely dispersed throughout the many facilities that support the NAVAIR Team. Generally, each of these separate laboratory elements has a special, often unique, function that is important to Naval aviation. Taken together these laboratory elements comprise an important national resource. MAIN/MAIL is a concept for enhancing and ensuring full utilization of the existing laboratory facilities throughout the Naval Aviation Systems Team community.

Modular Avionics Integration Laboratory (MAIL) describes a laboratory utilization approach focused on resources contained within a single Navy development center. Typically any networking done to support MAIL is accomplished by and within the range of a local area network (LAN). The Modular Avionics Integration Network (MAIN) extends the overall functionality of the MAIL concept by adding a networking capability to link Navy development centers that are hundreds or thousands of miles apart. The MAIN/MAIL concepts, taken together, create a broad basis for more effective utilization of existing laboratory resources on a full enterprise basis.

2.0 MAIN/MAIL Structure and Organization

The original organization structure for MAIN/MAIL consists of the NAWC Aircraft Division and NAWC Weapons Division development centers under NAVAIR, Avionics Department leadership. It is expected that as the concept is implemented and further evolves that other facilities (such as the Depots) will be integrated into the system. The fundamental organization is shown in Figure 1.

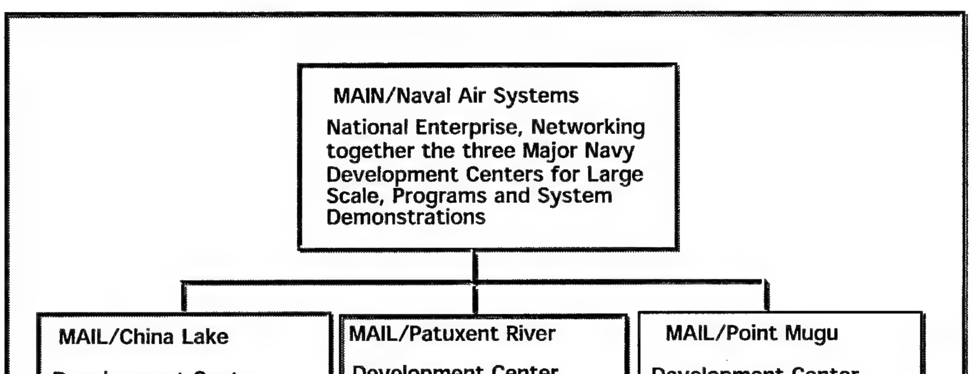


Figure 1. The fundamental organization of MAIN/MAIL

Figure 1 presents an organization that utilizes the fundamental functional work break down structure (WBS) that exists in the resources of the Naval Air Systems Command in establishing MAIN/MAIL. As shown, at a top level, China Lake is primarily responsible for weapons technology, weapons development and weapons integration. Patuxent River is primarily responsible for avionics technology and avionics systems concepts development.

Point Mugu has primary responsibility for electronics warfare and information systems technology and EW/IS systems development. This is a topdown, work breakdown, and generally true although elements of some of the major functional areas exist at other than the principal development center. The starting point for the MAIL at each of the development centers is to provide a laboratory system to support the development of key supporting technologies and their transition to operational systems. The laboratory is configured to support system development and developmental testing and evaluation. Each MAIL is intended to primarily support the functional/ technology area as defined locally at each of the participating development centers. The areas of technology specialization are shown in Table 1. The Avionics Department S&T Program (AIR-4.5T directed) Maritime Aviation Subsystems and Technology (MAST) Program has an identified focus for avionics technology and architecture research and is primarily administered and performed at Patuxent River MD. Each of the other Centers receive funding in the technology areas identified.

Navy Center	Technology Area
China Lake, CA	Weapons, Weapons Integ.
Patuxent River, MD	Avionics, Core Processing
Point Mugu, CA	Electr. Warfare, Info Sys.

Table 1. Technology Emphasis Areas at Navy Air Warfare Centers

The first purpose of each MAIL is to provide a facility to demonstrate and exercise products from Navy S&T initiatives in the technology areas assigned. It is expected that this utilization will help to make S&T developments more meaningful and facilitate effective technology transition. Additionally the MAILs serve as entry points for demonstrations of prototype technologies and systems (often proprietary) to the Navy. The MAILs also can serve as development testbeds for Cooperative Research And Development Agreements (CRADAs) and other joint development efforts with Industry, NASA, DARPA and the other military services in an attempt to broaden the business base for more effective utilization of Navy laboratories.

2.1 Networking between Centers: MAIN

The MAIN concept unifies the laboratory resources of the three Development Centers by providing effective networking between the individual MAILs. MAIN provides additional fidelity by making all resources: simulations, laboratory tools, etc. available for large system demonstrations and feasibility experiments. MAIN will utilize the network capability of the Defense Research Engineering Network (DREN), Naval Aviation Wide Area Network (NAVWAN) and other telecommunications links as needed. Although the distance between centers adds data latency issues, pseudo-realtime experiments can be conducted to evaluate basic feasibility for many systems problems. Figure 2 Illustrates the basic networking configuration envisioned.

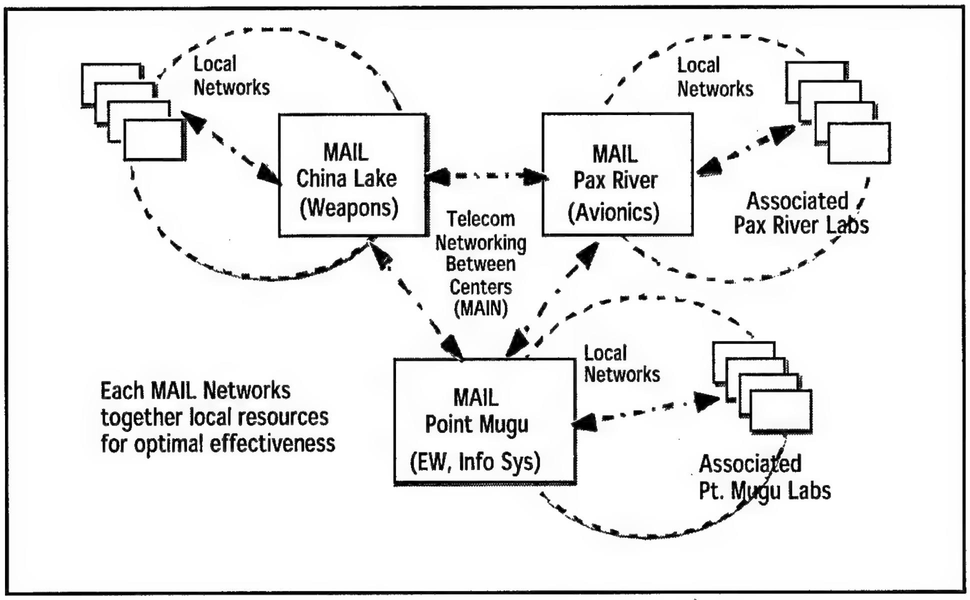


Figure 2. MAIN Networking between Navy Centers for Effective Laboratory Integration/Resource Sharing

Figure 2 presents a basic interconnection diagram. As the network evolves and the business basis expands, additional linkage to Navy Depots, Joint Service and Industrial sites is likely. The "network centric approach to warfare now being pursued is equally valid for the exploration, development process for weapon systems [1]. As conceived, each of the Centers would establish a "centerwide" MAIL to link local laboratory facilities as appropriate to satisfy technological and architectural needs within its areas of expertise. This local networking will utilize existing resources to the maximum extent possible, adding new facilities only as a last resort if needed to achieve overall capability.

2.2 MAIL/MAIL Leadership

AIR-4.5 has taken the leadership role for development of the MAIN/MAIL initiative. As the Avionics Department, AIR-4.5 is responsible for providing the engineering support to program offices responsible for the development and full life cycle support of avionics systems. This responsibility includes setting the policies for Navy avionics systems and assuring that the engineering disciplines required for the avionics "competency" are properly trained and available to the avionics program offices. The actual development and

acquisition activities are the responsibilities of the program offices that develop avionics systems and the platform program offices that utilize these avionics in aircraft and airborne platforms. However, these program offices of necessity must focus on a specific development. Overall avionics policy, avionics systems engineering procedures and processes, consistent avionics architectures and commonality/affordability approaches on a macro level are the responsibility of the avionics competency, AIR-4.5. To accomplish its mission, AIR-4.5 has initiated the MAIN/MAIL Program as a first step towards full integration of its laboratories into an effective National asset for avionics leadership for the Navy. Coupled with the laboratory network integration plan is an expanded business concept that embraces shared development activity with the Tri-Services, DARPA, NASA and Industry (both commercial and military).

Air-4.5 leadership believes that network based laboratory integration similar to that proposed will naturally occur over time on an ad hoc basis. MAIN/MAIL is a program to accelerate this process and assure that network integration is properly planned and effectively implemented.

2.3 The MAIN/MAIL Enterprise Team

A MAIN/MAIL Team has been formed to provide direct "hands-on" management of the concept development and implementation process. The Enterprise Team lead is William H. Schibler of AIR-4.5T. Other principal members are from each of the participating Navy Centers. Additionally, numerous others from involved focus laboratories, experts on networking and other technologies important to MAIN/MAIL are included on the Team. A considerable amount of work has taken place. Team meetings have been held at each of the participating NAWCS and through frequent Video Tele-Conference (VTC) status reviews. Many of the meetings have been held in parallel with laboratory tours to provide a more in-depth understanding of the many individual laboratory resources. Initial work of the Enterprise Team centered around the identification and classification of the many laboratory elements. A database describing each of the individual laboratories has been assembled as a starting point for implementation.

3.0 The Need

The underlying requirement for MAIN/MAIL is to provide a multi-functional avionics development and integration laboratory across the NAVAIR Avionics Department, AIR-4.5. The Avionics Department "competency". The MAIL provides an enhancement of the "core"laboratory capability in support of Navy Air program offices and Joint Service program offices. The flexibility and reconfigurability offered by MAIN/MAIL networking will complement the capabilities of existing laboratory resources and provide a "value added" to their utilization. The functional requirements for a laboratory system are somewhat volatile, changing in response to new, emerging, technologies and system architectural trends. Recent trends in systems engineering have emphasized the use of rapid prototyping techniques to synthesize and evaluate systems concepts more quickly and affordably. These trends and emphasis areas place great value on the versatility and reconfigurability that inter-laboratory networking provides.

At a top level, the mission for MAIN/MAIL can be summarized by the following key elements:

- Provide a framework to demonstrate and transition new technologies into current programs
- Provide a facility to support joint service programs, cooperative research and development projects with Industry, and shared initiatives with NASA, DARPA and others
- Support programs to develop advanced avionics architectures and systems concepts through Enterprise level S&T initiatives and investigations
- Serve as a resource to exercise and evaluate open systems standards and commercial off-the-shelf (COTS) products as candidates for Naval avionics systems and architectures
- Provides a "hands-on" capability for training of scientific and engineering personnel of the Avionics Department.
- Linking of the laboratory resources of the NAWCs and other NAVAIR facilities provides a structure for moving toward a common systems engineering process across the entire enterprise

Each of these key elements is discussed below:

3.1 A Framework to Transition S&T Products

Navy S&T programs are often criticized for failure to effectively transition S&T research into advanced development programs leading to in-service operational systems. Technology transition is difficult at best for a number of reasons. Workload and scheduling problems pose a major barrier to effective technology transfer. Program Offices find it difficult to make key personnel available to travel far and wide to attend S&T technology reviews. Further, it is often difficult to assess the risk involved with a new technology without significant additional evaluation. As a result, potentially useful technologies are often omitted because credible risk versus benefits assessments are not available. On the other side of the equation, those engaged in Navy S&T planning and administration have little budget or time available to engage in full scale marketing to and coordination with the potential user PMA community. As a result, much of the S&T activity is out of phase with program office needs in both content and timing. Recently there have been several efforts to provide better coordination between the S&T community and Naval Aviation Program Offices. Notable among these are the efforts of the Strike Vision Design Team (SVDT), established jointly by the Office of Naval Research (ONR) and the Naval Aviation Science & Technology Office (NAVSTO). Through joint efforts of members of the SVDT and the F/A-18 Program Office a process designated as the Advanced Technology Review Board (ATRB) process has been developed to identify and prioritize high payoff S&T programs [2], [3]. These efforts have been pointed towards a more effective, high payoff Naval research S&T program, coordinated with and integrated into the applicable PMA program roadmaps. The ATRB goal was to improve the ability of the Program Manager to implement emerging technologies in his platform. The ATRB process was originally developed by the SVDT in coordination with the F/A-18 Core Avionics Integrated Product Team (IPT). The process was first utilized by the F/A-18 PMA in 1997. A feature of the work done was that S&T products and continuing parallel S&T development efforts have been incorporated into the "outyears" of the F/A-18 roadmap, far beyond that done previously. To establish a much higher probability of effective technology transfer, the ATRB process has been extended to other programs and is currently being utilized for

S&T transition planning for PMA-201, Conventional Weapons [4]; and PMA-209, Air Combat Electronics. Information gathered using this process will be used as a basis for technology planning for the ONR/AIR-4.5T Maritime Aviation Sub-Systems & Technology (MAST) Program.

In addition to the improved efforts to coordinate S&T efforts with the needs of the PMAs, another problem encountered is that of achieving suitable exposure of advanced technologies and systems concepts to the appropriate PMA decision makers. It is expected that MAIN/MAIL can help to solve this problem. By providing laboratory facilities to demonstrate and showcase new technologies over an extended period of time, effective exposure to potential "customer" PMAs is much more likely to occur. Further, the MAIN/MAIL system can be used to perform the risk assessment versus benefits comparisons needed to justify the use of the subject technologies and/or systems. Long term usage of the MAIN/MAIL to host the products of S&T research, can so permeate the transition process that future S&T projects can be tailored to provide products to demonstrate in the laboratory. An extension of this concept can be used to assure that the products of S&T research are architecturally compatible and complementary to previous and parallel efforts. Consistent use of MAIN/MAIL can result in increased focus of S&T efforts so that the tendency is to create architectural structures that blend the key emerging technologies into effective systems.

3.2 A facility for an Expanded Business Base

Initial business planning for MAIN/MAIL has identified a number of potential customers for an expanded business base. Initially, it is expected that the business utilization for the laboratory resources from traditional customers will increase due to the added capability, architectural flexibility and increased fidelity provided by the networking provided. Additional business areas include the following:

- Integration/Development laboratory for PMAs; Emphasize commodity PMAs that do not currently have a core laboratory facility

- Increase in Programs that are shared between NAWC, Aircraft Division and NAWC, Weapons Division through use of the MAIN networking capability

- Provide a facility/capability to support key Navy IRAD programs

- Expanded participation in Multi-Service Joint programs

- Coordinated Programs with other Government Agencies; promote expanded efforts with NASA, the Defense Advanced Research Projects Agency (DARPA), FAA, et al

- Increased joint government/industry developments. Expand programs conducted under Cooperative Research and Development Agreements (CRADA), and Small Business Innovative Research (SBIR) initiatives.

3.3 Enterprise S&T Initiatives

The MAIN/MAIL laboratory resource provides a base for hosting Naval Air Enterprise S&T initiatives. Such initiatives become important when the Navy needs to evaluate a promising systems concept, but isn't certain of its overall value and hasn't any experimental basis on which to fully define the system requirements. In such instances the Navy isn't prepared to contract for an industrial development and needs an arena for experimentation and evaluation. Typically such enterprise projects involve a number of disparate technologies and system techniques, require multi-disciplinary skills and are larger in scope than the typical in-house S&T project. MAIN/MAIL can be utilized to host such focused enterprise programs and allow Navy engineers and scientists to determine the value and ultimately the requirements for such systems. One illustrative example might be to try out in combination a number of experimental Situation Awareness (SA) enhancing techniques that haven't been experimentally evaluated against Naval crewstation needs. The scope of the project could involve measurement of workload and situation awareness for different combinations of enhancement techniques, measured against Navy specific flight scenarios. A project of this scope could utilize rapid prototyping tools, pilot-in-the-loop (PITL) simulation and advanced processors and display generation equipment. The multi-disciplinary nature of the task would require a widely diverse Integrated Product Team (IPT) which would include human factors specialists, experienced pilots to participate in the evaluations, display and processor engineers and system development/rapid prototyping specialists. The product evaluations and any subsequent requirements generated can be explicitly tailored to Navy needs. The experience gained in projects of this type can provide valuable experience to the Navy practitioners involved and contribute to a more experienced, professional approach to any subsequent contractual development for integration into an operational platform.

3.4 Support for Standardization Activities

MAIN/MAIL provides a capability to support Naval aviation participation in avionics and electronics systems standardization initiatives. It is important if Open Systems Standards are to be effectively utilized that Navy personnel participate in standards development organizations and assure that the needs of Navy avionics systems are incorporated as standards are prepared, reviewed and revised. Key commercial standards organizations such as the Institute of Electrical and Electronic Engineers (IEEE) and the Avionics Systems Division (ASD) of the SAE are particularly appropriate. Figure 3 diagrams the standardization process that is appropriate for the needs of military avionics systems.

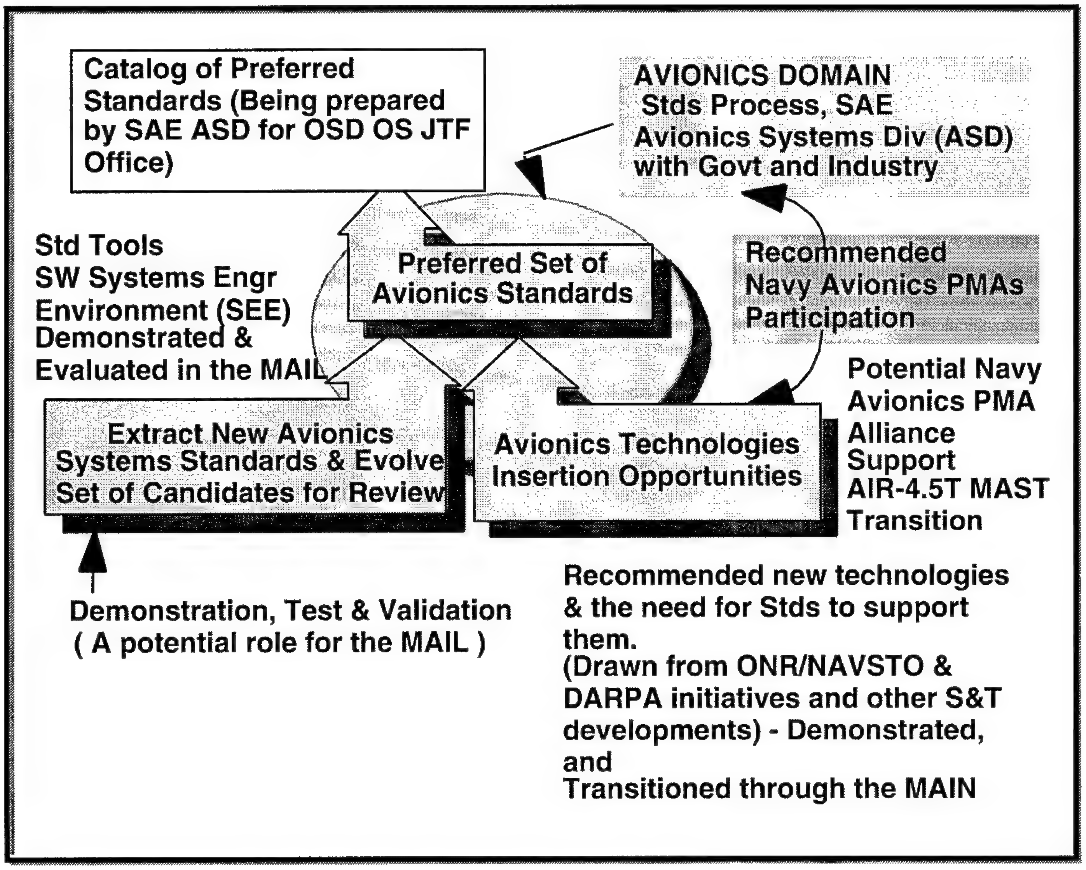


Figure 3. The Standardization Process and the role of MAIN/MAIL in Supporting a Navy role in Avionics standardization

As shown in Figure 3, standardization is achieved by selecting and supporting a system compatible set of avionics systems standards. The selection process, extracts systems interface standards from current avionics and includes them in a set of preferred standards. Figure 3 illustrates the process currently being employed by the SAE Avionics Systems Division in support of the DoD Open Systems Joint Task Force (OSJTF). ASD has been chartered to create a catalog of standards to populate the OSJTF Avionics Standards Domain. As shown in the figure, the standards are continually being updated as new requirements for avionics systems are defined and as new technologies are introduced. As shown in the Figure, it is expected that the Avionics Department, AIR-4.5 would participate in the review of standards and participate in the committees that develop and revise existing standards. MAIN/MAIL is viewed as a major supporting tool for this process, by providing the training that qualifies Navy representatives to participate in the standardization process. MAIN/MAIL also provides a test bed for evaluating Open Systems and/or COTS standards.

3.5 Training basis for utilization of MAIN/MAIL

Under AIR-4.5 leadership, the MAIN/MAIL can be utilized for "hands-on" training with avionics systems. Coordination among the three centers can assure that a cadre of in-house experts in all of the elements of avionics/airborne electronics will have laboratory facilities to maintain their expertise. Availability of MAIN/MAIL will support the effective transfer of expertise from senior technical personnel to new replacement personnel.

Future technical training can emphasize a "hands-on" knowledge of emerging technology by demonstrating new technologies directly in the laboratories. It is expected that "lessons learned experiences" gained through utilizing the MAIN/MAIL will be accumulated and provided as lessons learned for future training of avionics engineers and scientists.

3.6 Support of a Common Systems Engineering Process

MAIN/MAIL provides a framework for the development and implementation of a common systems engineering process throughout the Naval Air Systems Command laboratories. The integration process to prepare the laboratories to communicate and work together under MAIN networking, requires some focusing on standard interfaces, standard tools for requirements definition and analysis, and standardization of development processes. AIR-4.5 shares responsibility for avionics processes, and architecture definition with the Program Offices as part of its Avionics Competency responsibilities. A goal of AIR-4.5 is to achieve a greater degree of unity throughout the Avionics Competency. Joint participation of both NAWC, Aircraft Division and NAWC, Weapons Division in the development and implementation of a common systems engineering process will be a step forward in achieving greater national unity.

Systems Engineering Process Standardization

AIR-4.5 has prepared a set of reference guides/handbooks for systems engineering, computer resources, and other key avionics elements. It is proposed to use the existing handbooks as a starting point and enhance with specific documentation utilized at each of the centers. MAIN/MAIL provides an opportunity to unify the three centers through shared consideration and documentation of standard systems and software engineering process.

Standard Tools

A compendium of standard computer based systems and software-engineering tools will be pursued. Default standards, tools that are identified with certain elements and phases of the systems engineering processes will be identified and considered for adoption throughout the MAIN/MAIL laboratory elements. The goal is to unify the separate centers and systems engineers through common tools and common understanding of the tool utilization.

4.0 MAIN/MAIL Functions

The basic functionality of the MAIN/MAIL system is to provide a technology/systems demonstration facility with a rapid prototyping capability. The laboratory system is utilized for proof-of-concept and risk reduction studies and evaluations. Through its networking capability, the laboratory provides a great deal of flexibility and reconfigurability. Using networking, laboratory elements can be selectively chosen to create a laboratory architecture

that is consistent with the architecture of the system or system concept under development and/or evaluation. The complement of tools and resources necessary to satisfy the functional requirements of MAIN/MAIL include the following:

- "Hot Bench" capability to host prototype systems
- Architecturally broad, Proof of Concept test bed, Achieved by networking of various simulation, stimulation, and hardware in the loop resources
- Provide a Software/Systems Engineering Environment to support system development and integration.
- Necessary instrumentation and software based tools to support diagnostics and systems engineering functions

5.0 Definition and Implementation of MAIN/MAIL

Under direction of the MAIN/MAIL Enterprise Team, planning and early implementation has begun. Progress on definition and implementation of the MAIN/MAIL concept consists of a number of elements as described below.

5.1 MAIL Networking, Aircraft Division

Initial work at Patuxent River has identified the following candidate laboratories for a first phase linking under the MAIL concept:

• Mission Computers & Processors Lab	• Advanced Software Technologies Lab
• IR Systems Evaluation Facility	• Image & Signal Processing Lab
• Surveillance Radar Lab	• Crew Technology Lab, Sim. Facility
• Information Fusion Lab	• SAR Processing Lab
• EO Sensors Lab	• IR Project Spaces
• IR Engineering Lab	• Tactical Radar Exploitation Lab
• Crew Technology Lab, Mission Control Ready Room	• Air Combat Environment T&E Facility (ACETEF)

Table 2. Initial List of Resources for the Patuxent Aircraft Division MAIL Network

The laboratories listed in Table 2 are the initial candidates for MAIL networking at Patuxent River. These laboratories were selected because they are key in exploring advanced technology and system architecture development. The broad diversity of this set of laboratories suggests the many architectural variations that are possible as the laboratories are selectively interconnected on a project by project basis. The same sort of diversity exists at China Lake and Point Mugu as well adding numerous other technologies and system emphasis areas. At Patuxent River, a number of initial demonstration projects have been planned, utilizing a number of the laboratory resources identified in Table 2. Additionally, discussions are underway to link the facilities at St. Inigoes, MD to the Patuxent River laboratory and simulation resources and ultimately through MAIN/MAIL networking, to other laboratory and simulation resources at China Lake and Point Mugu.

5.2 Air Interoperability Center

At NAWC, Aircraft Division, Patuxent River, MD, the Air Interoperability Center (AIC) Project provides an infrastructure resource for linking together many key S&T laboratories and test facilities to better leverage their collective capabilities. The hub of this network is the Air Combat Environment T&E Facility (ACETEF), a tri-service DoD funded Installed Systems Test Facility that serves as the focal point for ongoing programs such as Joint Strike Fighter and Joint Theater Missile Defense. The AIC project consists of two key phases:

Phase 1. An ongoing MILCON-based task to install miles of high-capacity "blown" fiber optic cabling around the Patuxent River complex. The entire cable plant is certified as a "Protected Distribution System" (PDS) to allow the routing of classified scientific & engineering data between key facilities and buildings without the use of cryptographic equipment.

Phase 2. An extensive application development task to provide AIC application support for ongoing and new programs, leveraging the new PDS fiber optic system infrastructure. Efforts of the MAIN/MAIL team are being coordinated with the AIC project team in order to make maximum usage of AIC networking. Figure 4 provides a conceptual view of the AIC backbone network and its utilization to interconnect the laboratory resources of MAIL with other resources at Patuxent River. Figure 4 also indicates the external networking interfaces of AIC, which will be utilized by MAIN for interconnection outside the Patuxent River complex.

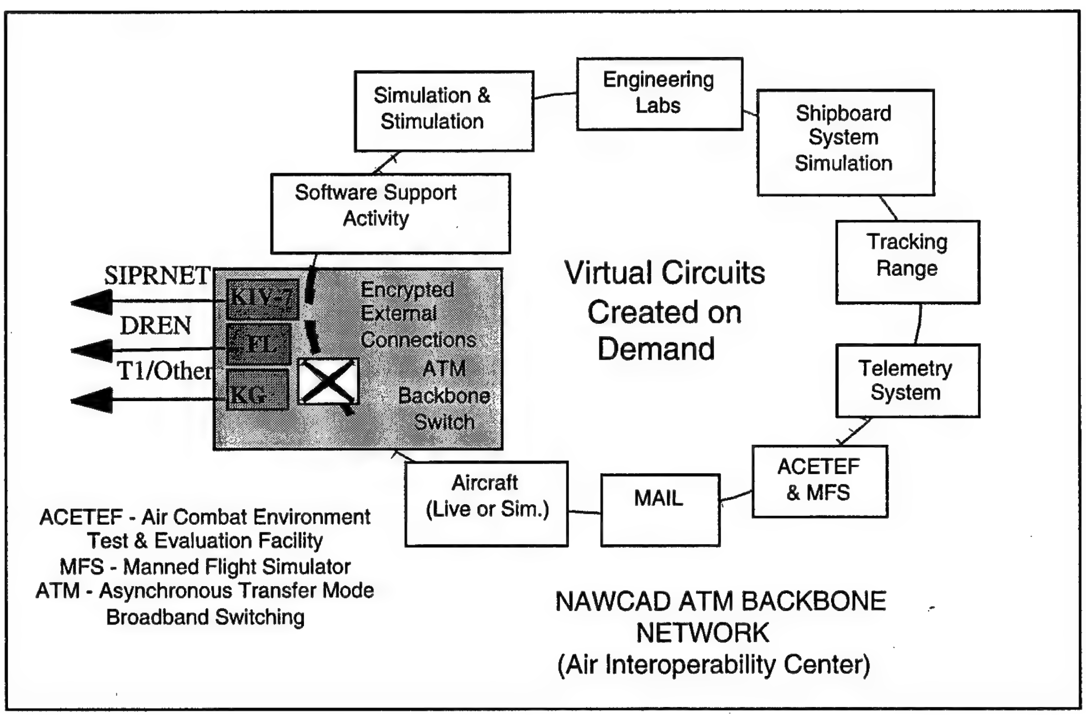


Figure 4. A Conceptual View of AIC Network Utilization

The AIC backbone network utilizes Asynchronous Transfer Mode (ATM) broadband switching. ATM is flexibly adaptable to many protocols using both real-time and non real-time engineering applications with LAN emulation and independent network control.

5.3 MAIL/MAIN Networking, Weapons Division

A number of resources at the NAWC Weapons Division (WD) have been identified for inclusion under MAIN/MAIL. These resources, both at China Lake, CA and Point Mugu, CA are listed in Table 3.

• Virtual Prototype Facility	• Inertial Development Lab
• Missile SIMLAB (IR, RF, HWIL)	• F/A-18 Weapons Syst. Support Facility
• F/A-18 Sensors Lab	• F-14 Weapons Syst. Integ. SIMLAB
• Range Control	• Missile Simulation Evaluation Lab
• Electronic Combat Range	• Data Link Lab

Table 3. Initial List of Resources for the Weapons Division (China Lake and Point Mugu) MAIL/MAIN Network

Many of the resources listed in Table 3 have been linked previously to satisfy program needs. T1 lines have been used to link resources between China Lake and Point Mugu in a number of joint simulation projects.

5.4 Demonstration Projects

A number of demonstration projects are planned to initiate MAIN/MAIL utilization. These projects will provide additional experience in linking multiple laboratory elements. The experience gained from these projects will be used to develop value added/return on investment projections for MAIN/MAIL. The following demonstrations are planned for 1998 and will be performed at the NAWC, Aircraft Division at Patuxent River, MD to demonstrate the viability of the concept. Each of the demonstrations requires additional networking between laboratories that will be provided as part of the MAIN/MAIL project.

Demonstration 1. Demonstrate Direct Coupling of Sensor Fusion Output Signals to Crew Systems Applications

This demonstration links the Information/Sensor Fusion laboratory with the Mission Computers & Processors Laboratory and with the Crewsystems laboratory. This demonstration will utilize COTS (Open System) processors to apply sensor fusion algorithms to sensor output signals and provide this information directly to the crewsystems simulators. This will allow validation of the sensor fusion algorithms and the ability of the COTS processors to handle the data. This demonstration will also provide a

more realistic crewstation simulation to resolve pilot workload and situation awareness issues

Demonstration 2. SAR Processing Directly Coupled to Crew Systems Display Lab

The Synthetic Aperture Radar (SAR) Laboratory has the capability of providing recorded "real-time" data to users as required. The data can be raw radar data as well as processed data. Utilization of a high-speed network connection will allow the data to be displayed remotely over the MAIN/MAIL networks. Networked to a series of using laboratories, SAR data can be utilized as part of a testbed for RDT&E to exercise technologies such as processors, displays and data fusion techniques. Distributed SAR data can also be applied to such applications as mission planning, battlespace awareness, intelligence, surveillance and reconnaissance.

Demonstration 3. EO/IR Lab Coupled to Crewsystems Display Lab

This demonstration will add networking between the EO/IR laboratory and the Crewsystems Display laboratory. This interconnection will enable the testing and evaluation of multi-spectral data display (combining of multi-spectral data on a single display) and sensor fusion by the combining of EO/IR and /or radar and/or LADAR data. This demonstration will also provide for the testing and demonstration of COTS hardware and operating systems to meet the needs of sensor specific signal processing algorithms on real sensor data.

Demonstration 4. Tactical Radar Lab Demonstration conducted with Industry

This demonstration will be performed under a CRADA with Northrop-Grumman Baltimore. Under the CRADA, Northrop-Grumman will provide an AN/APG-66 (F-16) radar system to the Tactical Radar laboratory at Patuxent River. The Tactical Radar laboratory will then be linked to a number of laboratories that can utilize tactical radar data. This laboratory was never intended to be networked, so the addition of external networking will add significantly to its utility. Additionally, the laboratory possesses some unique Non-Cooperative Target Identification (NCTI) processors that will interface to the AN/APG-66 radar. Under the terms of the CRADA, the radar will be available for R&D and/or the Test and Evaluation of new hardware and software components

6.0 Architecture Concepts and Issues

In 1993, the Naval Air Systems Command published a study of advanced avionics architecture and technology trends [5], [6]. One of the key findings of this study was that because of the diversity of Naval aircraft missions, a single architecture won't satisfy all applications. Although, a single architecture won't suffice, it is important that the Navy agree on a minimum number of standard architectures in order to achieve the economy of scale necessary to realize affordable avionics. As a result, system architecture is an important avionics concern. Some architectural standardization is required to effectively utilize integrated/highly modular avionics. The following sections address a number of important architecture issues, many of which are closely coupled to the effective utilization of MAIN/MAIL.

6.1 Standard Architecture Concepts

In order to achieve the economies of scale offered by standardization, it is important that standard architectural approaches be adopted where justified. Although no single architecture can satisfy all applications, if a standard development process is adopted, common tools are utilized and a core set of standard interfaces can be agreed upon, systems developed will exhibit an architectural consistency that will promote more affordable systems. It is the purpose to establish common architectures for avionics, weapons control and integration, electronic warfare suites and information systems. Through MAIN/MAIL development and utilization it is proposed to establish these common architectures and look for as much commonality as possible among the specific sub-architectures. The goal is to achieve an overall architecture of airborne electronic systems that serves to integrate avionics, flight controls and displays, EW/IS systems into a consistent architecture to emphasize commonality and minimize integration engineering issues.

The common architecture framework provides consistency in transitioning S&T products and provides a basis for more affordable common avionics systems. This architectural standardization must be coordinated with standardization activities of SAE, INCOSE and others, achieving standardization jointly with military and industry representation. A standard architectural platform will provide a reference for evaluation the suitability of COTS standards and COTS products.

6.2 Avionics Architecture Trends

For the last twenty-five years or so, military avionics systems have been characterized by use of federated systems architectures. In these systems, avionics functions have been packaged as discrete subsystems, often in separate enclosures or "black boxes". System integration has been accomplished primarily by busing together the separate sub-systems to create a complete avionics suite of equipments. The principal integration tool has been the standard aircraft multiplex data bus, in its current version MIL-Std-1553B. This bus provides the basic integration function through a "command-response" protocol. Employing, a twisted-shielded pair transmission system, MIL-Std-1553 has provided effective system integration beginning with the F-16 and continuing to current aircraft such as F-15 and F/A-18. The federated architecture has allowed avionics systems to be readily partitioned into separate sub-systems that can be separately developed as "commodities", each with an integral MIL-Std-1553B interface capability, The multiple sub-systems can then be brought together and integrated through use of the standard multiplex data bus. As a result of the predominant federated architectural approach, the Navy has created a business organization that is directly compatible. Organizationally, the commodity PMAs have been created to address the needs of important separate or discrete functional areas. An important examples is PMA-209, Air Combat Electronics which includes products in communication, navigation, information systems and flight avionics. Some other examples include PMA-233, Mission Planning; PMA-209, Aircrew Systems; and PMA-272, Electronic Warfare.

In the last ten years or so, the inadequacies of the federated architecture have become apparent. The MIL-Std-1553B data bus, primarily a control bus, has been asked to carry increasing amounts of data. Its 1 Mb/Sec bit rate is wholly inadequate for modern systems data requirements. Even for systems in which Mil-Std-1553 is retained as the control bus,

it must be supplemented by additional high-speed buses/networks to satisfy data transfer requirements. As a result of this and other trends, avionics architectures have transitioned to what is described as a modular/integrated architecture. Figure 5 provides a graphical representation of the architectural transition described.

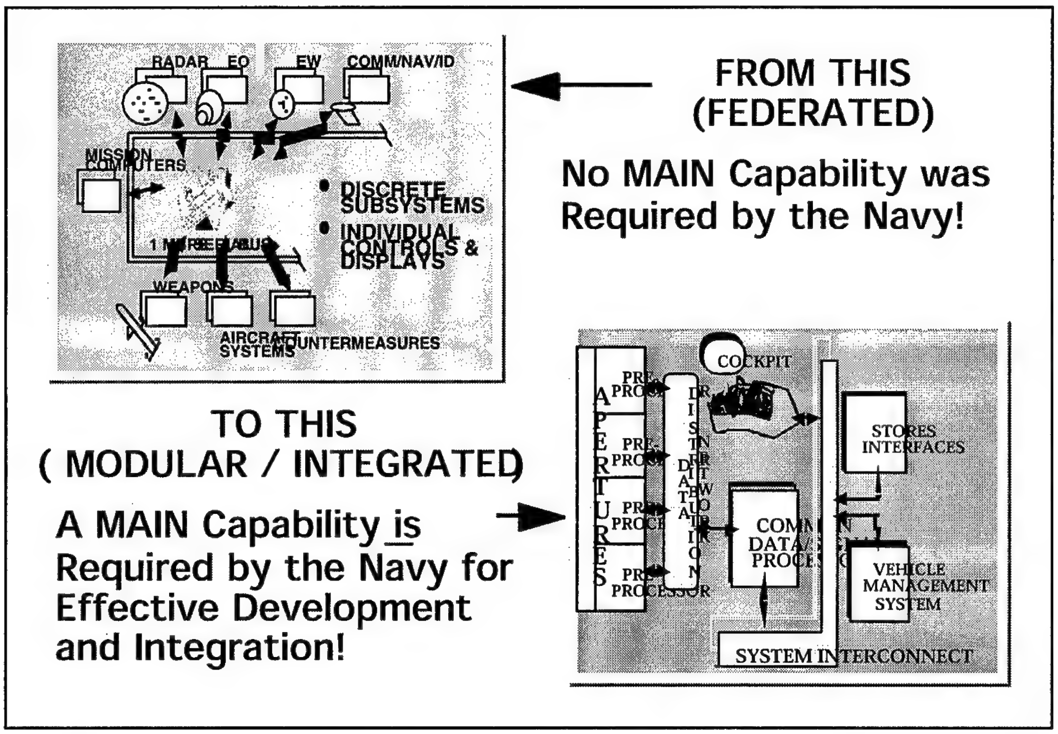


Figure 5. Graphical Representation of the Federated to Integrated Architecture Transition

As shown in Figure 5, the integrated architecture is highly modularized and consists of banks of similar processing elements. The architecture is driven by advances in microcircuit integration, which today provides processing power at a module level that once comprised a complete sub-system and required a separate electronic enclosure. Rather than utilize discrete cabling between separate sub-systems, integrated architectures rely heavily on module to module transmission lines often packaged into module backplane structures. Such systems emphasize high pin-count modular connectors with high frequency signal transmission over controlled impedance structures on the backplane. The elements of these architectures are closely coupled and highly interactive. A great deal of architectural flexibility is possible and fault tolerance/avoidance can be built in by

reallocation of resources or utilization of spare resources to minimize catastrophic failure modes.

The nature of advanced modular/integrated architectures is such that coordination between avionics commodity PMAs to agree on architectural structures, interfaces and modular standards would be very helpful. Such higher-order architectural agreement would promote a greater degree of architectural compatibility and functional interoperability between the various products of the avionics commodity PMAs. The MAIN/MAIL laboratory system provides a facility to perform the demonstrations and system integrations necessary to establish such common architectures.

6.3 System of Systems Avionics

An important role for the MAIL/MAIN is to support the integration process for advanced avionics systems. The term "system of systems" has been applied to large-scale system concepts at every level. When applied to avionics, it has come to indicate a number of major functional sub-systems integrated into a single "super-subsystem". System of systems avionics integration takes advantage of advances in microcircuit integration levels (with circuit feature sizes moving into the sub-micron level) and advances in packaging and interconnection technology. System of systems avionics integration is applicable both to new designs as well as some retrofit applications. In retrofit applications, advances in microcircuit integration allow an original sub-system enclosure to be replaced by an updated enclosure of similar volume. The internal avionics of the updated enclosure consists of an advanced modular architecture, which combines multiple functions together in the space formerly occupied by a single function. The system of systems approach is therefore particularly applicable to implement an avionics retrofit/upgrade architecture. Figure 6 illustrates the system of systems process in s flow-chart diagram form.

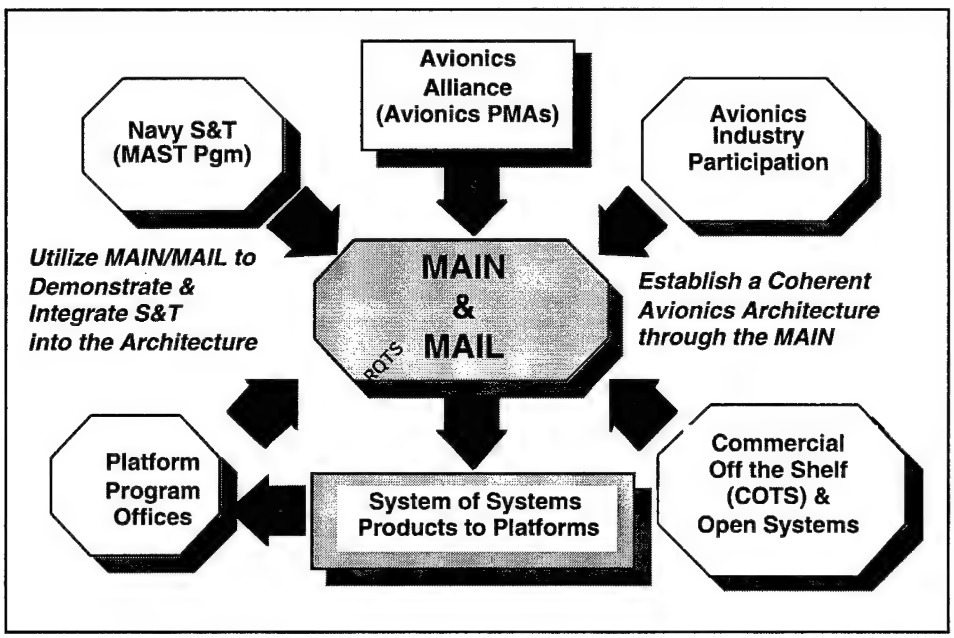


Figure 6. Avionics System of Systems Process

As shown in Figure 6, the MAIN/MAIL system can provide an integration framework to support system of systems avionics integration. As shown, the MAIN & MAIL is utilized as a development/integration laboratory under direction of the appropriate avionics PMA or jointly under several cognizant avionics PMAs representing the several avionics functional areas being integrated. Figure 6 illustrates how S&T research and technology products can be introduced and transitioned into the system of systems product. As a government laboratory resource, MAIN/MAIL allows industry to participate directly or through shared

CRADAs. Coherent system architectures can be established, integrating appropriate Open Systems/COTS products as appropriate. Coordination can be achieved between the cognizant avionics PMAs and the customer platform program offices with MAIN/MAIL providing the framework to resolve requirements issues.

7.0 Status and Future Plans

This concept that led to MAIN/MAIL implementation was first proposed in the fall of 1996. In the Spring of 1997, a leadership team was assembled from NAVAIR, NAWC Aircraft Division and NAWC Weapons Division, and the project was formally initiated, In July, 1997 a Request for Information (RFI) was issued, soliciting information regarding industry interest in the concept and desire to participate. A number of internal Navy briefings were given to develop support and initial funding for activities of the team. By use of video teleconferencing, frequent team meetings were held and activities were coordinated among the several sites. Development plans have been formulated and several preliminary steps have been completed. An assessment of available laboratory resources at the three sites has been performed and a database has been compiled. Networking planning has been initiated for the system. At Patuxent River, The AIC project has been utilized to provide the basic networking "backbone" for that site. In 1998 a number of demonstration projects have been initiated to demonstrate the potential utility of the MAIN/MAIL system.

A business plan to ensure an expanded business base for utilization of the networked laboratory system is in preparation. Preparation of a Concepts of Operations (CONOPS) guide has been initiated and will be updated and revised as the demonstration projects are completed and provide lessons learned.

As the system is demonstrated and implemented, a marketing effort will be put into place to expand the customer base. This will include a follow-up RFI to industry to initiate partnering efforts, and CRADA initiatives.

As the MAIN/MAIL system becomes operational it is expected that the activity will be made available to other elements of the AIR-4.0 Engineering Department, including AIR-4.1 Systems Engineering, AIR-4.6 Crewsystems, and AIR-4.7 Weapons as well as to AIR-5.0, Test & Evaluation.

8.0 Summary and Conclusions

This paper has provided an overview of the MAIN/MAIL initiative and its present development and implementation status. Through a discussion of its potential utilization we have attempted to place the significance of such a capability into full perspective. As discussed, MAIN/MAIL can be an important tool for the NAVAIR Avionics Department to satisfy its goal of greater coordination and unity throughout the Avionics Competency. It is expected that full implementation will provide a laboratory capability that significantly enhances the Navy's ability to conceive, prototype and fully develop and integrate the advanced avionics systems required to fulfill future missions.

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Title: Foundation Initiative 2010

Presenter: Mr. Rick Cozby
Headquarters, U.S. Army Test and Evaluation Command
ATTN: AMSTE-TM-T
Aberdeen Proving Ground, MD 21005-5055
(410) 278-1481, fax ext. 1475
rcozby@tec1.apg.army.mil
Track: Joint SIT-SDT

ABSTRACT

The Foundation Initiative 2010 (FI 2010) project is an interoperability initiative of the Director, Test, Systems Engineering and Evaluation, Office of the Under Secretary of Defense (Acquisition and Technology), funded through the Central Test and Evaluation Investment Program (CTEIP). The Army is the lead service for execution, with Navy and Air Force support. The FI 2010 effort is postured to improve systems development, testing, training and fielding through the application of object-oriented systems interoperability between simulations, hardware-in-the-loop (HITL) test laboratories, live/operational tests, and training systems. The FI 2010 concept builds on High-Level Architecture (HLA) and Test & Training Enabling Network Architecture (TENA) standards and includes a core set of tools, inter-range communication capabilities, interfaces to existing assets, a repository of reusable software and procedures for conducting an object-oriented exercise.

FI 2010 serves as the foundation upon which ranges will want to build their future investments. Therefore, the development strategy relies upon partnering with ranges from the beginning, and this is accomplished through the creation of development test cells and coordination with Range Commanders Council and the Common Test and Training Range Architecture working groups. This paper provides an overview of the FI 2010 project and supplies details of the objectives to be accomplished in FY 98. These include tests and assessments of the simulation and federation object model development tools provided by the Defense Modeling and Simulation Office and a synthesis of requirements for a universal, flexible display engine with reusable components. They also include a check-out of the latest HLA runtime infrastructure and a Hardware-in-the-Loop to Open Air Range interaction investigation involving the Naval Undersea Warfare Center, the Air Force Development Test Center and the Naval Air Warfare Center. A video documentary of this investigation will be provided as part of the paper presentation.

1.0 Introduction

The Foundation Initiative (FI) 2010 project responds to Defense Science Board recommendations to establish standards, facilitate interoperability, and fully internet test and training ranges and facilities.

FI 2010 also responds to the increasing use of Modeling and Simulation (M&S) in general and to the Simulation Based Acquisition (SBA) and Simulate, Test, Evaluate Process (STEP) initiative of the Under Secretary of Defense (USD) for Acquisition and Technology (A&T) in particular. The architecture and products delivered by FI 2010 are intended to:

1) Reduce duplication and the cost of procurement and maintenance of range instrumentation and software.

2) Facilitate the integration of T&E and training range assets across multiple ranges.

3) Facilitate the integration of live, virtual and constructive simulations to create the larger, more complex, and more realistic test and training battlespace environments demanded by modern weapons systems and tactics.

The FI 2010 Project was established at the beginning of Fiscal Year (FY) 1998 at the recommendation of the Test and Evaluation Reliance and Investment Board (TERIB). It consolidated four existing Central Test and Evaluation Investment Program (CTEIP) Projects: the Test and Training Enabling Architecture (TENA), Common Display and Processing Systems (CDAPS), Virtual Test and Training Range (VTTR) and the Joint Regional Range Complex (JRRC). The products and commodities developed will entail concepts that foster extensive software reuse, use advanced computational developments, and exploit distributed interactive simulation techniques and commercial-off-the-shelf technologies (COTS), where applicable. The products will include sets of common, integrated software capabilities and processes to significantly improve the capability to configure and re-configure instrumentation resources to acquire, network, process, display, and archive data in support of T&E missions and training exercises.

The Full Operational Capability (FOC) to be provided by the FI 2010 architecture and products is notionally referred to as the Logical Range—a set of live, constructive and virtual resources assembled into a system of systems to support a specific test mission or training exercise. The Concept of Operations (ConOps) for the Logical Range is defined in the document of the same name dated March 1997 (Draft).

A simple example of a logical range is illustrated in Figure 1. The Navy Synthetic Environment for Tactical Integration (SETI) program integrates high fidelity torpedo simulation capabilities with live Fleet submarines operating at depth and speed on range. Using SETI, a submarine can fire on a live target using the Hardware In The Loop (HWIL) torpedo in the Weapons Analysis Facility (WAF) at the Naval Undersea Warfare Center (NUWC) Division Newport. Both firing and target submarines can "see" the simulated torpedo in real-time while submerged thus allowing for weapons wire guidance and target evasion. With planned connectivity enhancements SETI will provide simulated targets, countermeasures and ocean environments. The benefits of SETI include unlimited availability of virtual torpedoes to support crew training and torpedo hit or miss assessments, capabilities previously unavailable or unaffordable.

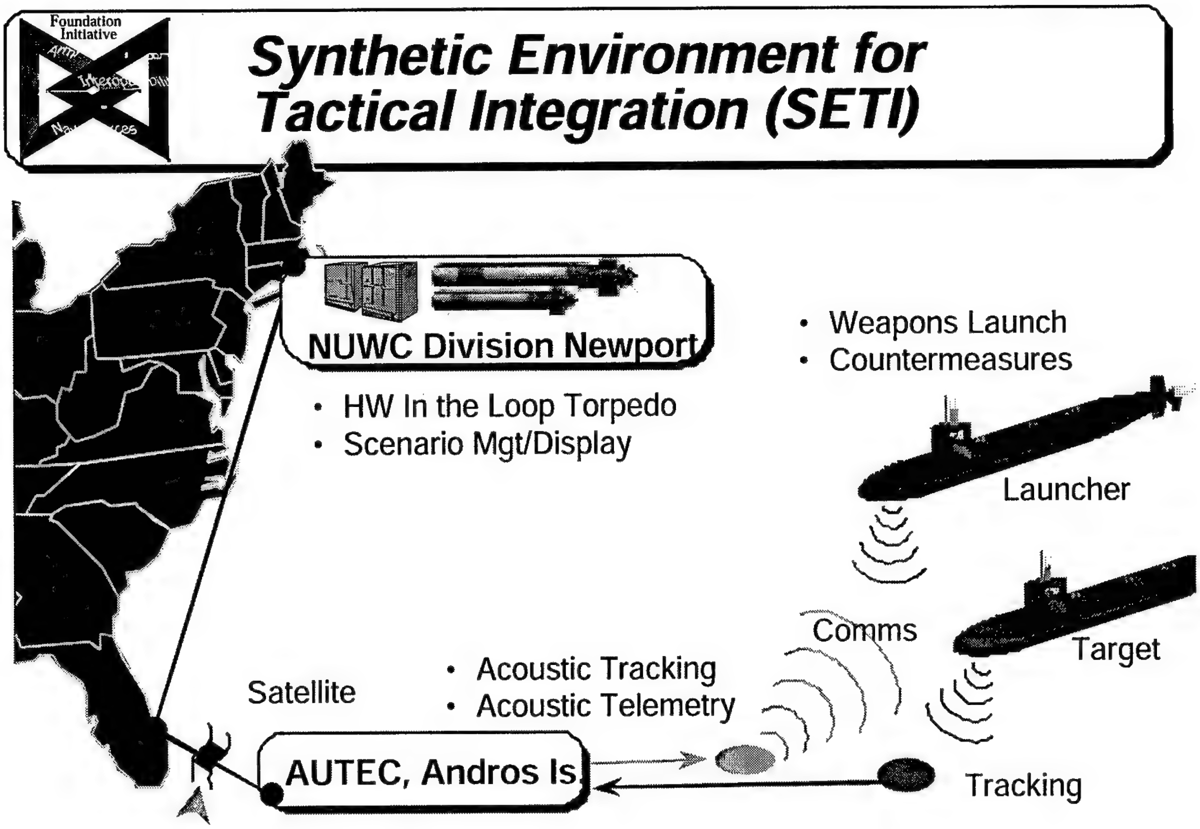

Figure 1. Synthetic Environment for Tactical Integration Exercise

The SETI project is one of three FI 2010 exercises to be conducted in FY 98. The remaining two are illustrated in Figures 2 and 3 below. Their purpose is to gain broad-based insight into the utility and feasibility of conducting distributed synthetic and live testing and training events using a common architecture and reusable software tools. The FY 98 exercises focus on linking hardware-in-the-loop facilities and open air ranges, and each investigates alternative configurations, interfaces and procedures.

The Joint Advanced Distributed Simulation (JADS) System Integration Test (SIT) II is a follow-on to the Advanced Distributed Simulation (ADS) test conducted in FY97 by the JADS Joint Test Force. Using HLA instead of a Distributed Interactive Simulation (DIS) implementation, the JADS SIT II replicates the original JADS SIT risk mitigation test scenario, linking the Pre-flight Integration of Munitions and Electronic Systems (PRIMES), the Guided Weapon Effectiveness Facility (GWEF), and the Central Control Facility (CCF) at the Air Force Development Test Center, Eglin AFB, FL. Operated and maintained by range personnel, a Development Test Cell (DTC) emulating the Major Range and Test Facility Base has been established to cost-effectively develop, test, and validate the software interfaces and exercise tools in a controlled environment. Toward our ultimate goal of range interoperability and reuse, the JADS SIT II exercise serves to be an integral step – generating comparison data to past DIS methodologies, identifying potential HLA shortfalls to be rectified by Test and Evaluation Enabling Architecture (TENA), and providing insight (when combined with results from other exercises) to the common aspects among ranges and facilities ideal for standardization.

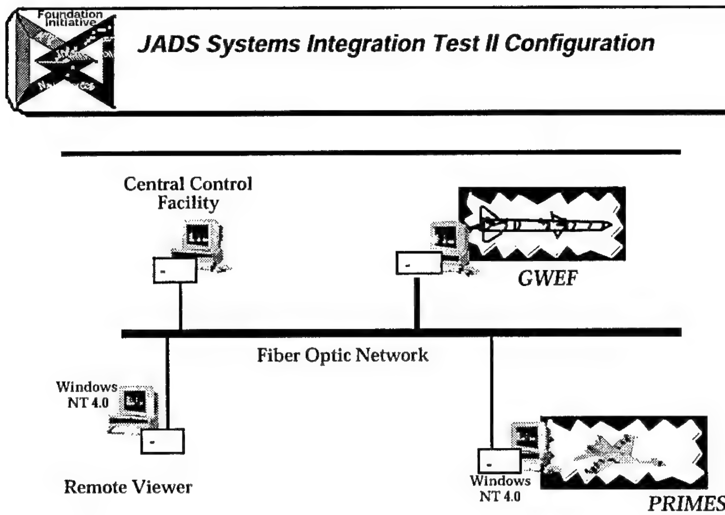

Figure 2. Joint Advanced Distributed Simulation (JADS) System Integration Test, Version II

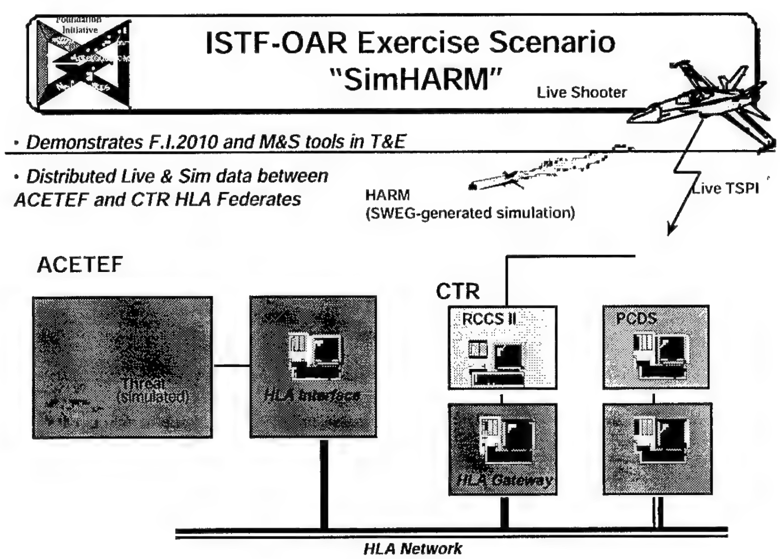

Figure 3. Simulated High Speed Anti-Radiation Missile (SimHARM) Exercise, Linking an Installed Systems Test Facility (ISTF) to an Open Air Range (OAR).

2.0 The Need for a New "Foundation"

The conceptual framework for military operations defined in Joint Vision 2010 is of size, scale, and scope that cannot be physically, technically, or economically recreated within the existing DoD Test and Training infrastructure. DoD Test and Training facilities have heretofore evolved autonomously, resulting in duplication of effort and resources, differing processes and procedures, and wide variations in the age, type, and capability of basic Test and Training resources such as instrumentation, computers, software, communication systems, and data displays. These variations limit the interoperability, sharing and reuse of resources demanded by the Joint Vision paradigm. In addition, the increasing use of modeling and simulation in support of acquisition streamlining portends a new era of duplication and disparity if a interoperability common framework is not established soon. A clear advantage of using modeling and simulation in test and evaluation is the potential to conduct distributed operations across a common network. To make this happen, participating models and simulations must have the ability to interact, and FI 2010 is charged with developing a promulgating the capabilities that will make this interaction practical.

3.0 FI 2010 Architecture and Products Characteristics

The FI 2010 architecture and products are designed to support the full spectrum of Test and Training facilities including Open Air Ranges (OARs), Systems Integration Laboratories (SILs), Hardware in the Loop (HWIL) Facilities, Measurement Facilities (MFs), Installed System Test Facilities (ISTFs), and constructive, live, and virtual Models and Simulations.

Several characteristics are required to foster interoperability, sharing, reuse and multi-domain polymorphic applications. Many of these characteristics are key to successfully implementing the logical range concept. All play a role in reducing duplication and cost in range infrastructure developments and in providing the desired multi-domain applicability to support the full spectrum of Test and Training facilities.

3.1 Distributability

The FI 2010 architecture and products will support execution on multiple hardware platforms that are geographically distributed and connected via one or more communication networks. Multiple users will be able to access data from various databases in order to plan potential exercises, and will be able to query potential participants about their availability and current or projected operational capabilities.

3.2 Extensibility

The architecture will also allow LR components to be easily upgraded or modified to support add-on requirements without requiring restructuring of the existing architecture. Add-ons could include providing more and/or different workstations from which planning and exercise control would be conducted, incorporating new data networks, including new sensors, and weapons and/or models to simulate them, etc.

3.3 Interoperability

Systems, units, or forces must be able to provide and receive services from other systems, units or forces, and to use the services such that they can operate together effectively. Interoperability is a system characteristic, which allows the assets of one test or training facility to be used and controlled by one or more other facilities "on demand"; as seamlessly as if they were an integral part of their organic systems.

3.4 Modifiability

The FI 2010 architecture and products will support, to the maximum extent possible, the ability of a hardware or software component to be easily modified to perform various tasks, to operate within new systems or environments, or to adapt to changes in scope or magnitude of performance requirements. Modifiability often depends on an item's modularity and use of standard interfaces and is normally more easily achieved with software. As an example, to be modifiable the simulation of a sensor or weapon system must provide for the various performance parameter values to be determined by preset and easily changeable data files/tables rather than "hard" coded.

3.5 Portability

This is the ability of a system, hardware or software component, or data to be easily transferred from one hardware or software environment/system to another. This requires the existence and use of common interfaces so that hardware/software components and data can be easily inserted into various environments/systems with minimal reformatting or interface modification. FI 2010 will assist in the development of commercial standards to promote development of common interfaces needed for portability.

3.6 Reusability

Reusability is the ability to use the same products and capabilities at multiple ranges and facilities. An example product might be a graphical display software package. Other examples may include processes, procedures and documentation templates (e.g., design, test, standards). Reuse supports a common-core of a product that is, in fact, exactly the same from instance to instance of that product, and it also supports the ability to adapt the reusable product in predetermined ways at the level of a local instance. Reuse is distinct from commonality in that commonality implies every instance of the reused product is exactly the same. Effective reuse is an optimization of commonality and flexibility that recognizes the unique requirements of individual ranges and facilities within a common core environment or domain. Reuse enables significant savings in long-term development and maintenance costs and is an effective and efficient path to sharing and interoperability.

3.7 Scaleability

Scaleability is the ability to use the same architecture and application software on many different classes of hardware/software platforms from personal computers to supercomputers and for tasks varying in scope and complexity (extends the portability concept). The capability to handle various operations of greatly different scales of operational requirements and to be able to easily grow to accommodate increased workloads beyond the initial capability. An example of scaleability in the LR context is to be able to run a single vehicle exercise at a single range or a multi-vehicle exercise at multiple ranges and other facilities with the same basic system.

3.8 Sharability

The FI 2010 architecture and products shall support sharing which is defined as the ability of one facility to directly use the products generated by another facility. Interoperability is the most extensive form of sharing, but is not the only form. This definition of sharing includes a variety of "one-way" information exchanges where data or data products are sent to many facilities, but control of the data generation is strictly at one source. An example of this capability is the effective transmission of post-test analysis products without custom translation required for each product user.

3.9 Usability

The FI 2010 products will enable the LR users to perform their tasks effectively and efficiently. A usable system is can be used by a variety of system operators for a variety of tasks. Although operators may have unique or specialized skills (e.g. test conductors, flutter engineers, graphics operator, etc.), they should not need special training to use those skills via standard system interfaces. Operator interfaces will be "friendly," and operators will be able to perform their tasks following the instructions and guidance provided in manuals or on-line help. Operator entries will be by point and click (mouse, track ball, etc.), pull-down menu selection, keyboard, or other simple interface device.

4.0 Operating a Logical Range

The FI 2010 architecture and products will support the ability to rapidly define, setup and execute a logical range and its associated battlespace environment for a test mission or training exercise by assembling and managing the necessary resources from a pool of available live, constructive, and virtual resources. Regardless of whether the particular resources used for a given event are actual or simulated, the objectives of the event are the same: to accurately test and / or evaluate the performance of a system under test (SUT) or training participant under a certain set of conditions. This is accomplished, usually in a stand-alone mode today through the use of numerous T&E and Training support resources known commonly as OARs, SILs, HWIL facilities, MFs, ISTFs, and M&S facilities. Meeting the objectives of reducing duplication, facilitating the integration of T&E and training range assets, and facilitating the integration of live, virtual, and constructive simulations requires that the capabilities to define, setup (configure), and operate the assets (e.g., instrumentation, environment generators, stimulators) be drawn from a common framework. This is also true for the assets used in conducting post-event analysis.

4.1 Defining a Logical Range

Current methods of defining the specific assets of T&E and Training support resources are predominantly unique to the particular resources being considered. Referring back to the SETI experiment as an example, the means for defining what torpedo information needs to be available during the conduct of that exercise (e.g., speed, heading, position) would be different for: an actual firing of a torpedo at AUTEC (underwater 'OAR'), a simulated torpedo launch in the WAF (HWIL facility), or a synthetic torpedo launch in a M&S facility. This could potentially be true for all of the participants required for a particular LR instance (i.e., test mission or training event). Recognizing that the cost of defining the assets required for a logical range operation must be significantly less than the current, aggregate cost of defining these assets for stand-alone operations, the logical range will provide the definition capabilities as described below. These capabilities will be common among the various resources being assembled for a logical range operation and transparent to the user with respect to the specific resource from which the asset is being identified (eg., OAR, HWIL, or M&S based).

Resource Asset Identification. This identification capability includes asset attributes such as name, type, location, input data, and output data. An example of a resource asset would be a radar (of type FPS-16 with output data of range, azimuth, elevation, and time).

Resource Asset Definition. A logical range resource asset definition allows a logical range operation planner to define, where necessary, the operation unique resource asset information. An example of such an asset would be a telemetry system. The format of the input stream, the processing to be applied to each raw data item decommutated from the stream, and the engineering units of the resulting data items are specific to a particular logical range operation.

Resource Repository. This repository shall includes typical data base capabilities to store, search, retrieve, copy, and modify entries. Entries will consist of the resource asset identification and definition information. It will also ensure that information is provided in a FI2010 compliant format.

Resource Browser. A resource browser capability allows remote access to the resource repository. This access capability will be available via existing community desktop computer systems (i.e., no logical range-specific or unique equipment).

Logical Range Definition Capability. This includes the means to assemble resource assets from the resource asset repository in accordance with the specific requirements of a mission or exercise. It includes the capability to designate primary and secondary resource assets to accommodate the rapid reconfiguration of a logical range due to failures and scheduling conflicts associated with designated primary resource assets during LR operations.

Logical Range Repository. This repository will include typical data base capabilities to store, search, retrieve, copy, and modify entries. These entries will consist of logical range instances stored via the logical range definition capability. It shall also ensure that information is provided in a FI2010 compliant format.

Logical Range Definition Utilities. The following utilities will be provided to support the logical range definition capability:

Performance Prediction. This utility shall analyze the resource asset interactions defined

for a particular operation and identify potential performance discrepancies. This shall include items such as network bandwidth, missing data items, mismatched data item formats, and mismatched data rates. Using the SETI experiment as an example, the position of the launching submarine would be identified as a missing data item were it not defined for the AUTEC range asset as it is a required input to the torpedo systems of the WAF asset. A mismatched data item format would be detected if the AUTEC range asset defined the submarine's depth in feet when the WAF is defined to accept it in meters.

Network Simulation. This capability provides the means, based upon the resource assets and network assets defined for a particular LR operation, to simulate the planned LR network. This simulation capability provides the user with the capability to identify potential bandwidth, latency, protocol, and general LR asset interaction discrepancies of the actual operation but without directly utilizing the physical resources.

Logical Range Configuration File Generation. This capability generates the files required to configure the assets for a specific logical range defined within the logical range repository and selected by the user.

4.2 Logical Range Setup

Logical Range Setup capabilities will include:

a. Scheduling. Scheduling capabilities facilitate planning for the execution of an exercise or test on the logical range. Scheduling capabilities will accommodate, to the maximum extent practical, the various scheduling and accounting systems in use at DoD and contractor ranges and facilities.
b. Network Setup Support. The Network Setup Support Capability will support the translation of the logical network defined during the logical range definition phase into the physical network required to execute the logical range task. The Network Setup Support Capability will also support testing of the physical network prior to execution.

   Test Capabilities will include:

   1) Component Compliance Test. This capability will be used to support testing of each simulation for compliance with its definition and with the definition for the logical range before interaction is attempted with external simulations.
   2) One-on-one Interaction Testing. One-on-one Interaction Testing capabilities will support testing the interactions between each pair of components in the logical range definition to ensure that interactions occur as expected.
   3) Many-on-many Interaction Testing. Many-on-many Interaction Testing capabilities will support testing the interactions that are expected between components in the exercise environment.
   4) End-to-end Testing. End-to-end testing capabilities will support testing the interactions of all resources in the logical range. End-to-end testing is a complete rehearsal of the test/training exercise scenario.

4.3 Logical Range Execution Management

Logical Range Execution Management will include:

a. Logical Range Control. Logical range control capabilities will provide for human control, monitoring, and visualization of the LR during the execution of its resources. These include Resource, Network, Initialization, and Execution applications.

b. Logical Range Monitors. Monitors support the Control capabilities and will support monitoring the real-time operation of the logical range. Logical range monitors include:

   1) A Network Traffic Monitor to display status and control the flow of messaging on the logical range network.

   2) A Message Monitor to monitor and keep track of the message traffic between the various resources of the logical range.

   3) A Data Monitor to track the data being captured, perform quality checks, and display data on request.

c. Visualization Capabilities. Visualization capabilities will support the display of standard tactical, three-dimensional viewport, and graphical data and events and are used both for real-time visualization of events and post-test review and analysis.

d. Data Logging and Archiving. Data logging and archiving capabilities will support the capture and storage of data for playback and analysis.

4.4 Post Test Mission /Training Exercise Analysis

Post Test Mission /Training exercise analysis capabilities will include Playback, Data Extraction, Visualization, and Data Definition capabilities:

a. Playback Capability to reconstruct exercise or test events from messages and data logged during the execution of the logical range.

b. Data Extraction Capability to extract specific data elements or events selected from the data logged during the execution of the logical range.

c. Visualization Capabilities to support data analysis uses the same visualization capabilities used for logical range execution management.

d. Data Definition Capabilities used to characterize the data during the logical range definition phase also support post test/exercise analysis.

5.0 Summary & Conclusion

Obviously, the task of reinventing the test and training infrastructure is not for the faint of heart. The technical issues are vast and complex, but they are meager relative to the cultural and organizational issues, which this paper does not begin to address. There indications, however, that the time may be right to begin the discussion. The Defense Modeling and Simulation Office

(DMSO) High Level Architecture (HLA) and other DoD M&S initiatives, such as the Synthetic Environment Data Representation & Interchange Specification (SEDRIS), the Modeling and Simulation Resource Repository (MSRR), and the Master Environmental Library (MEL) are positive steps toward improved interoperability. In addition, DoD Manual 8320.1-M-1, Data Standardization Procedures, dated November 1996 (Draft) and the DoD Range Commander's Council (RCC) Data Interchange Standard, DR-19, are important resources for achieving this end, as the Joint Technical Architecture (JTA) and Defense Information Infrastructure (DII) Common Operating Environment (COE).

Initial Operating Capability (IOC) for FI 2010 is defined as the completion of a Joint Test Exercise (JTE) that successfully demonstrates the FI 2010 architecture and core set of products. However, during the execution of the FI 2010, products supporting the functionality of the LR will be developed and delivered incrementally to the ranges and facilities. Full Operational Capability (FOC) is to be determined; however, it is anticipated the FI 2010 architecture, products and the logical range concept of operations will continue to evolve indefinitely after IOC, funded by non-CTEIP mechanisms.

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HANDS-FREE AVIONICS MAINTENANCE SYSTEM (HAMS)

Authors

John J. McFadden - Supervisory, Electronics Engineer
(301) 342-9133
Richard Rosa – Project Leader, Electronics Engineer
(301) 342-9148
Neil Abramson - Computer & A-V Specialist
(301) 342-9150

Michelle Windsor – Electronics Engineer
(301) 342--9158

Naval Air Warfare Center - Aircraft Division
Avionics Systems Integration Branch, Code 4.5.1.2
Building 2187 Suite 2180
48112 Shaw Rd. MS 5
Patuxent River, MD. 20670

Track

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Abstract

This paper describes ongoing efforts by the Avionics Systems Integration Branch, Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland to integrate wearable computers, into an aircraft maintenance environment. This Hands-Free Avionics Maintenance System (HAMS) includes state-of-the-art technologies such as voice recognition, wireless Internet services and remote video teleconferencing.

The aircraft maintenance system also entails converting the existing paper based legacy data, i.e., technical manuals and maintenance record cards (MRC's) into electronic data stored on an Internet server. This data would be organized and accessible by the various maintenance tasks performed and multimedia-enhanced, providing the technician with text, graphics, video and animation. The same multimedia database could then be used to both train the Aircraft Maintenance Technician (AMT) and to assist the AMT on the flight line performing maintenance procedures.

Keywords

Aircraft Maintenance, Wearable computer, Internet, Video teleconferencing, Wireless LAN, Tele-maintenance

I. Introduction

The Naval Air Warfare Center at Patuxent River, MD is developing an integrated system to support the diagnosis and repair of aircraft that utilizes wearable computers for the U.S. Navy. Specifically, the development team is working to bring aircraft Interactive Electronic Technical Manuals (IETM's), electronic maintenance/inspection procedures and video teleconferencing to the flight line for the first time. This combination of wireless, wearable technical data, distributed via Internet from a central site and "expert" aviation diagnostic and repair advice dispensed to geographically remote sites via teleconferencing enables repair of aircraft and their complex avionics subsystems independent of the squadron's deployed location. The anticipated benefits of this effort will be a reduction in maintenance and repair times, improved aircraft availability, and a reduction in the support cost factors associated with the aircraft flight line maintenance activities and document distribution.

II. The Need for Improved Maintenance Practices

Navy avionics maintenance is currently a paper and manpower intensive process. Technical manuals, daily and periodic maintenance check lists are all distributed via print media (paper and laminated card stock). As document printing and publishing budgets continue to be reduced and as warehousing costs for paper documents continue to rise, printed documents are updated and distributed less and less frequently. The conversion to digital media will mitigate these problems along with providing updates in a more timely fashion.

Current manpower issues center on the cost of sustaining "subject matter experts" at each squadron location. Historically, whenever a squadron encounters a problem beyond the capabilities of the organic maintenance staff, the "experts" are consulted on the site. At remote sites the squadrons often lose the services of many of their field service representatives who are located in the U.S. These "experts" advise the squadron during their more complicated maintenance tasks but are not routinely deployed to remote locations. If complex problems arise a "tiger team" is dispatched to address them. As maintenance budgets also decline, the Navy is facing the challenge of finding alternatives to the dispatching of "expert tiger teams" and to sustaining "expert" staff at each U.S. based location. The Avionics Systems Integration Branch anticipates the wireless wearable Web services will assist the Navy in addressing both the paper and manpower issues. Based on the prototype system that we have developed, we anticipate that a wearable computer system with network connectivity will provide the required functionality and performance at a cost-effective price.

The HAMS concept addresses two major needs. The first is Affordability: the HAMS will meet the need to develop systems, processes and technologies that result in reduced manpower. The HAMS will also meet the need to develop new/improved maintenance techniques and processes - with on-line technical assistance at-sea and ashore. The second is Information Support: the HAMS will meet the need to develop techniques to increase the portability of computer-based maintenance and training systems.

The requirement to reduce operations and support costs is universal across all aircraft platforms. Reduction of these costs at the organizational level with the use of the HAMS would provide a sizable cost saving. The Navy has started the process to provide Interactive Electronic Technical Manuals (IETM's) for the maintenance technician. However, IETM's on laptop computers still miss the mark with problems such as sunlight readability, probability of being dropped and are generally inconvenient to use. While newly developed flat screen displays that do very well in bright sunlit areas are within a year of being introduced, an important requirement is not achieved. That requirement, to allow maintenance personnel to have the data they require and at the same time not restrict their maintenance actions by tying their hands to a PC or flat panel display is addressed by the HAMS concept.

Several portable computer technologies support the concept. Laptop devices, including rugged versions, can provide access to technical information and be linked via wireless LAN configurations to information and personnel. However, only the body worn ("wearable") computers afford "hands-free" access and control, providing complete mobile functionality (see Figures 1, 2 and 3). The wearable together with voice recognition software and high-resolution displays worn over the eye or mounted on the body will produce a truly hands-free environment. For example, the AMT can "ask" the computer for a torque rating of a particular bolt, and receive a response form the computer, while keeping both of his hands on the torque wrench. Both the hardware and software for wearable systems has evolved to provide the required levels of functional performance and affordability. Similarly the wireless LAN components have matured to the point where they may be considered as both cost effective and functionally acceptable. Realization of the concept requires the adaptation and integration of these diverse elements to achieve a system support tool that will amplify the effectiveness and results of the individual maintenance technician and inspector in carrying out their assigned duties.

Figure 1
Via, FlexiPC

Figure 2
Interactive Solutions, Mentis

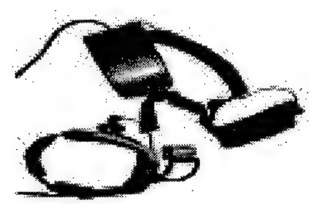


Figure 3
Xybernaut, Mobile Assistant

III. System Description

A high level pictorial of the Tele-maintenance Concept is depicted in Figure 4, Hands-Free System Maintenance System Concept. This figure portrays the AMTs equipped with the HAMS units, linked with the maintenance shop via wireless LAN, which in turn is supported by other logistics systems and communication links to the Internet and remote technical support systems and personnel.

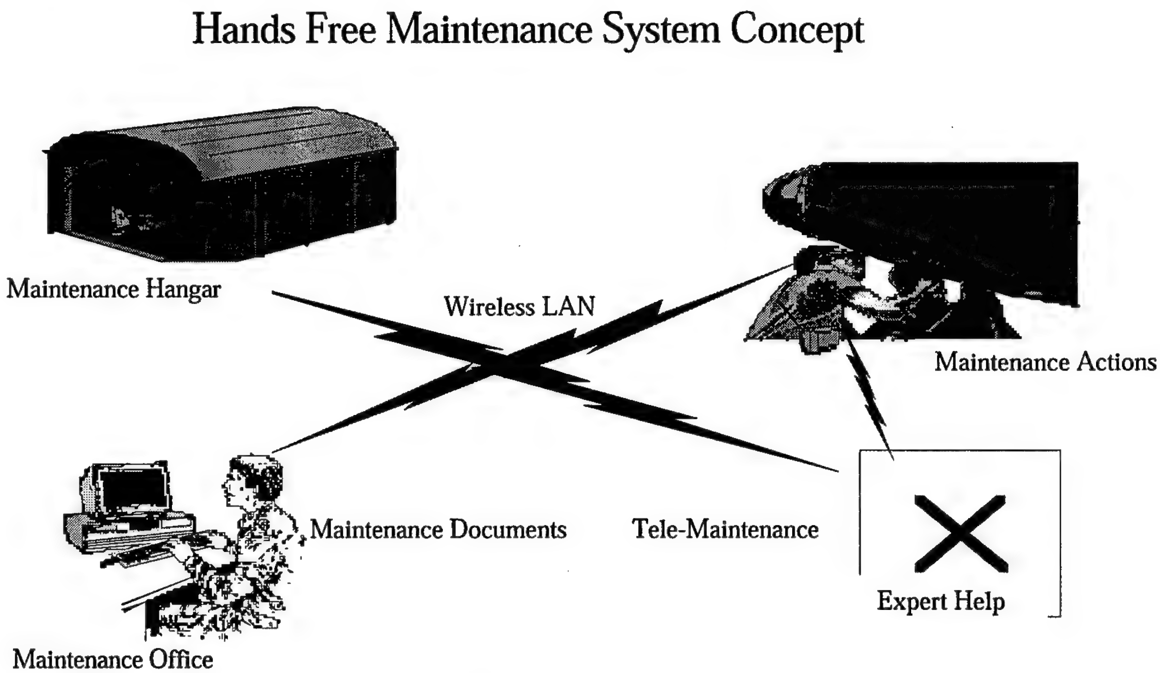


Figure 4

The HAMS will provide a portable integrated inspection and maintenance support system for the AMT'S using wearable computing devices, voice recognition software, wireless communication links, operational software and interfaces to legacy support systems. The heart of the HAMS is a lightweight state-of-the-art wearable computer, which contains a 3GB+ Hard drive, 64MB RAM, wireless PCMCIA card for LAN/Internet connectivity, display, microphone and a earpiece speaker.

As with any new system, the most critical and costly element is the development of the software. In the case of Avionics maintenance, the majority of information is contained in paper-based manuals and MRC's that will need to be converted to an electronic based format. In the few instances where platforms have electronically-based manuals, we are faced with developing one of a kind transition tools to convert proprietary software. Fortunately, the NAWC has funded an SBIR with Via, Inc. that has identified some of these problems and developed tools that can be used to convert the proprietary software.

The choice of software in which avionics maintenance information will be contained is certainly the most critical decision. Past lessons learned, point to the fact that proprietary

systems are the most costly to maintain. It is critical that the software used in the HAMS is accepted as a worldwide standard. At the recent (May, 1998) NetWorld+Interop, UUNet Technologies, Inc. President and CEO, John Sidgmore cited in his keynote address that Internet traffic is at a 1,000 percent growth rate. Mr. Sidgmore stated that he believed that Internet traffic would soon consume half the available bandwidth on networks worldwide. By 2002, the percentage will climb to 90 percent, and in 2008 Internet traffic will account for 99 percent of the data traversing international networks. While it is impossible to predict the future, we believe Mr. Sidgmore is going to be on the mark. There should be no doubt that any database that is assembled for avionics maintenance should be designed, stored and accessed on an Internet/Intranet server. As aircraft manufacturers develop their information in electronic formats such as scanned images, word processing outputs, tagged data files (SGML, HTML), the Navy must be able to accommodate these documentation variants into its own structure. The HAMS will integrate legacy manuals and documentation into portable and accessible Internet readable electronic formats, and augment the information with Internet friendly audio, video, graphics, and various viewing aids.

For inspection purposes, the HAMS system will display Maintenance Requirement Card (MRC) procedures and provide for the entry of data and text inputs. MRC's will be displayed on the wearable's display monitor with all attendant required documentation. Each procedure will require compliance and, where defined, electronic signature verification or approval from pre-assigned validations and supervisors. Support documentation, such as Operator's Manuals, will be available in electronic format. Just-In-Time training video clips for primary procedures will be available. Completed inspection scenarios will be uploaded via wireless communication networks directly from the flight line to a local inspection data base.

For maintenance purposes, the HAMS system will provide computerized assistance in determining causality from accumulated symptoms. This assistance will be provided in the form of decision trees as presently structured manually within existing Maintenance Manuals, and eventually evolve into expert rule based algorithms for specified equipment types. The HAMS can also support detailed problem data collection and analysis through the use of plug-in modules that provide direct connection to digital data bus message traffic and measure electronic signal characteristics. Advanced capability will provide for the direct interfacing of the HAMS to a digital data bus for evaluating mission avionics status. Discrepancy reports can be downloaded directly from the local data base on the flight line through the use of wireless communication links. Automatic logging of maintenance actions and parts used will be a system capability.

IV. Benefits

The aviation community, both civilian and military, has recognized the need to change their current maintenance techniques and move toward more cost-effective alternatives. Contemporary maintenance methods and programs are driven by factors of cost and performance integrity. New approaches that fare favorably in a cost/ benefit analysis will receive primary consideration for implementation. Consequently any device, procedure or system that can address cost and performance issues will receive due consideration. The Avionics Systems

Integration Branch has determined that the use of wearable computers to support the HAMS concept presents significant cost reduction opportunities and enhances compliance levels for safety related inspection/repair procedures.

The introduction of wearable computers to U.S. Navy aviation maintenance sites is expected to positively impact affordability in seven specific areas:

(1) Reduce inspection manpower for scheduled inspections

(2) Reduce inspection skill level requirements.

(3) Reduce flight line maintenance manpower for normal maintenance and repair actions

(4) Reduce mean time to repair.

(5) Reduce logistic support manpower levels.

(6) Decrease maintenance training costs.

(7) Reduce flight line parts sparing levels.

The Tele-maintenance concept in conjunction with wearable computers offers a dramatic potential for performance enhancement of maintenance personnel. A variety of factors contribute to the performance improvements, including several already identified as cost factors. No one factor appears to dominate the list, however, controlled studies currently underway will provide hard metrics to validate the perception. However, immediate and obvious advantages to Tele-maintenance include both reduced numbers and skill levels of personnel. Currently situations arise where multiple maintenance personnel are required simply because of the work location and the attendant need to access maintenance documentation or information. Wearable computers in a "hands free" operating mode have been demonstrated to reduce the need for additional staff in most situations. In addition the access to amplifying information and Just in Time Training (JITT) in the form of "show me" videos or graphics supports the use of less experienced personnel, even for more complex tasks. An associated feature of this approach is the ability to reduce the formal training requirements for staff resulting in both reduced training costs and expedited availability of maintenance personnel to the field.

Procedural consistency is promoted by hosting procedures, checklists and forms on the wearable computer, and controlling the order, data access and monitoring of the inspection and maintenance processes. Both results and performance metrics can be acquired to support the establishment of training requirements and procedure modifications. Furthermore, access to a centralized database can be used as a means to promote the expedited update to procedures and documentation, and the accelerated distribution of corrected information.

It is recognized that the wearable computer has a powerful role in affording access to information and accommodating diagnostic tools such as plug-in test equipment and data bus analyzers, and local "expert" system support programs. However, the Tele-maintenance concept elevates the role of the wearable computer to another dimension by affording a real time link to maintenance experts at the design and manufacturing levels of the system under evaluation.

Through video conferencing the systems experts can be literally at the side of the maintenance technician supporting the diagnosis and repair of the system under test. This is expected to have an amplifying effect on the performance levels of the field personnel for those problems that are beyond the routine.

V. Current Technology Challenges

The Wearable PC shown below in figure 5 is the Via III. It is a future generation wearable PC on a belt that contains a Pentium class processor. This is only one example; Companies such as Interactive Solutions and Xybernaut will surely follow in developing small wearable PC's. While it is easy to envision a wide array of uses for the wearable PC, several related technologies will need to grow before we reach the wide spread use of the wearable.

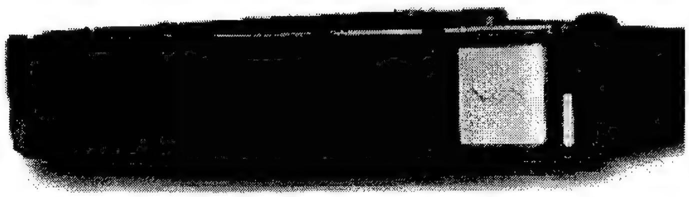


Figure 5

Via III

A. Wearable PC's

The keystone of our efforts is the wearable PC. In the almost three years that we have worked with wearable PC's, a marked change has occurred. The wearable has been reduced in size and weight by almost fifty percent. The processor has gone from a 486-33MHz to a Pentium 133 MMX, to the recently announced 233MHz Pentium II Mobile chip. Memory has increased from 24MB to 64MB and disk drives have gone from 500MB to 3.1GB.

While the above are all major enhancements, manufacturers must work to dissipate the heat generated by the high-speed Pentium chip. The Pentium CPU has provided the wearable PC with the processor speed needed to handle a variety of tasks, particularly in the area of voice recognition. Unfortunately, the tremendous increase in CPU speed has caused a great increase in temperature. During our testing, we have recorded temperatures as high as 140-degree on the surface of the wearable PC. While Intel has stated that the Pentium can run at 130-degree temperatures and above, recent versions of the chip have required laptop manufacturers to install up to four small fans to cool the chip. In the case of the wearable this problem is very serious since fans cause the size to grow and use battery power. As processor speeds and therefore temperature increase it will be critical that we reach a solution to this problem. A recent demonstration by Fujitsu Electronics, showed a fan with a tube that moves the heat out of the case, dropping temperatures by at least one-third.

Although the wearable shown in Figure 5 is ergonomically a good solution, the user would like an even smaller lighter wearable PC. In addition to following the technical advances of wearable computer manufacturers, we are watching closely the downsizing of laptop computers and the upsizing of Windows CE devices. It is our vision that all PC vendors are converging on a wearable PC that can be carried/worn unobtrusively and that will provide connectivity to the Internet. The wearable PC will be a part of our everyday lives, providing us with information and communications services.

B. Battery Technology

While great strides have been made to reduce the size and weight of batteries, most wearable applications require an eight hour "run time," i.e., constant availability throughout the workday. While a user will accept charging the battery each day, the user will not accept gracefully "shutting down" the wearable to put in a new battery during their workday. Batteries must continue to shrink in size and weight, while allowing additional run time.

We have tested Nickel Metal Hydride (NiMH), Lithium Ion (Li-on) and Nickel Cadmium (NiCd) batteries along with power management software. While our goal has been an eight-hour battery life, the dramatic increase in CPU speeds and the power consumption of a color display have prevented us from meeting our goal. We had great hopes for greatly increasing battery life when we heard about Intel's "Tillamook" mobile CPU, which had a greatly reduced power requirement (from 3.4 to 1.8 volts). Unfortunately, the chip's increased processing speed negated most of the power saving, providing us with only a 30-minute increase in battery life. We are told by battery manufacturers that new technology, which will be in the market in the next three to five years, will solve our problems, but for now the user must "wear" two batteries to attain the desired eight-hour operation time.

C. Voice Recognition

Microphones are a key component for proper voice recognition. Open boom mikes typically pick up too much noise for acceptable voice recognition. Head-mount, "close-talk" microphones, especially those enhanced with active noise canceling circuitry, have been highly successful in a typical laboratory or office environment. However, there are problems with voice recognition in high noise environments with these types of microphones. It is also important to note that the variety of commercially available speech engines will perform differently in high noise environments. Earpiece microphones use a unique device that incorporates a microphone and speaker in a molded form to fit into the ear similarly to a hearing aid device. The ear microphone senses vibration of the ear bone when the user speaks, and the molded earpiece provides an excellent means of blocking external high level noise. We are also evaluating throat microphones, which wrap around the throat to pickup vibration, and skull microphones, which rest on top of the user's head usually as part of a helmet assembly.

Voice recognition technology will need to improve both in its ability to recognize an extensive vocabulary and to recognize words spoken by a wide range of individuals. The ability to use our voice in place of the keyboard and/or mouse is most critical in that the wearables will not be a "hands free" device until voice recognition becomes second nature to the user.

Specifically, we are looking for a low cost speaker independent Windows NT/Internet Browser compatible voice recognition engine which offers high (>90%) recognition in high ambient noise environments. We have performed extensive testing and research in the area of voice recognition. Voice recognition products from Texas Instruments, IBM, Microsoft, Verbex and Dragon Systems have been evaluated. While voice recognition software and noise canceling microphones have improved, the greatest jump was made with the introduction of the Pentium. With a 133MHz. Pentium and above, we have achieved a voice recognition capability of 98 percent in low ambient noise environments. We are now searching for a solution to achieving a high rate of recognition in high ambient noise situations, such as the flight line or in a hangar.

D. Optical System

Improvements to optical functionality and comfort are needed. In the best of today's systems, the optical system is "in the way" of the user. It either hangs in front of the user or is wrapped around their head making the wearable uncomfortable when worn for more than a short period of time. Optical information will need to be made available in an unobtrusive display that will be comfortable to the user, while displaying high definition information. Specifically, we are looking for a SVGA/PC compatible display that can be head or body mounted, adjustable for eye dominance and focus.

A Head Mounted Display (HMD) of particular interest was exhibited at the International Symposium on Wearable Computers, held during October, 1997. The HMD designed by MicroOptical Corporation, shown in figure 6, appear to be a normal set of eyeglasses. In fact, what MicroOptical has developed with funding from DARPA and the Army is a normal set of eyeglasses that include a concealed electronic display. When the user wears the glasses and turns the display on, an image of a video or computer screen appears at a distance of several feet. A focus adjustment allows the user to place the image at a comfortable distance.

The eyeglasses perform the same functions as ordinary corrective lenses, sunglasses, or safety glasses. Additionally, the glasses provide the user with a convenient, portable means for carrying a display that may be connected to a wearable computer or other electronic device. Such eyeglasses are expected to become increasingly important as wearable electronic products enter the market.

A computer, VCR, television, or other electronic device generates a signal that carries the image electronically up to the eyeglass frame. A small liquid crystal display is used to

generate the image that the user sees. The light rays from the liquid crystal display are relayed to the eye through reflectors within the eyeglass lens. The reflectors fold the optical path and magnify the image so that it can be viewed comfortably. The user perceives an image floating in space at an adjustable focal distance of three feet or more.

When the display is turned off, the computer image disappears and the glasses revert to ordinary glasses. The user can see through the eyeglass lens.

The technology includes prescriptive correction. MicroOptical has demonstrated eyeglasses with an approximate correction of -5 diopters, and most prescriptions should work well.

The image presently provides 320 by 240 pixels with 8-bit grayscale. The field of view is approximately 8 degrees (horizontal). A color display has also been demonstrated. While stereo glasses are not currently being developed, the technology can be applied to both lenses in the eyeglasses to form a 3D image.

The eyeglass lens is unique in the manner that the computer image is brought to the eye. Specifically, there are no external lenses or other optical components so that the eyeglass lens can be inserted into an eyeglass frame having ordinary appearance. The electronic circuits are built into the temple of the glasses. While the electronics are currently contained in a very small pod on the side of the glasses, MicroOptical intends to conceal all of the electronics and optics in the eyeglass frame.

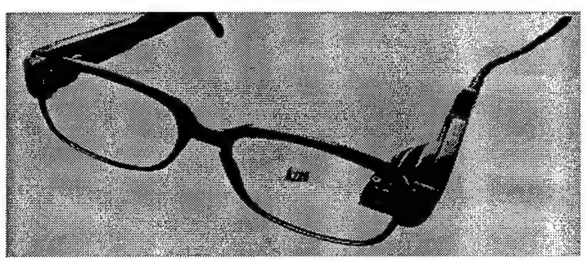


Figure 6

MicroOptical Eyeglass Display System

E. Wireless Communication

It is a certainty that high bandwidth wireless connectivity to the Internet must be attained in the development of a hands free computing environment. While many of us are quite familiar with analog or digital cell phones and some of us even exchange data using Cellular Digital Packet Data (CDPD) through your local carrier, its maximum rate of 19.2Kbps will not fulfill our mission requirements.

The mission requirement to send and receive voice, data, graphics and video to the Internet generates a minimum need for a rate in Mbps or a T-1 rate (1.55Mbps) and beyond. This requirement is not impossible to meet, but unlike the simplicity/low cost of CDPD, reaching T-1 rates and beyond is met with technical roadblocks and/or can be quite costly.

In meeting our requirement we first considered infrared (IR). While the original IR standard permitted a maximum of 115.2Kbps, the Infrared Data Association (IrDa) has recently approved version 1.1, nicknamed Fast IR. Fast IR will transmit information up to 4Mbps. The big drawback is the fact that IR needs line of sight and while this requirement can be met in an controlled environment such as an office, and while hubs/repeaters could used, connectivity would be very difficult to achieve in the world of avionics.

We next considered Radio Frequency transmission methods. Unlike IR, even a low power 100mw signal can reach 120 feet indoor and several hundred feet outside. To overcome "shadowing" when the user steps inside the aircraft or the aircraft is between the user and the server we found suitable locations to "hang" repeaters on both sides of an aircraft. In testing we found that highest rate that we achieved with a T-1 rated PCMCIA card in a wearable was 600Kbps, while this was a great improvement over cellular packets, we were disappointed in its inability to reach true T-1 speeds. While we could send and receive graphics and streaming video, the need for greater bandwidth was apparent when more than one client requested video streams from the server. We then tried a similar wireless LAN solution with PCMCIA cards that were rated at 10MBps. While this configuration showed great improvement, we found that when multiple users attempted to link back to the server, performance was not at an acceptable level. We decided to pursue this solution we would need to work with industry to develop a PCMCIA card with a low power transmitter that would have a bandwidth greater than 10Mbps.

The final consideration was that of Satellite Transmission. While military satellites do exist and information can be sent at Asynchronous Transfer Mode (ATM) speed (155Mbps) and beyond, we found that availability and cost issues caused us to put this solution off until availability and costs become realistic in terms of our requirements. We decided to determine what other satellite platforms were available. Motorola has a project named "Iridium" that calls for the launch of 66 low earth orbit satellites in the fall of 1998. We were disappointed to find that the bandwidth was only 2.4Kbps. Other low earth orbit satellite projects, such as Teledesic, are only a few years away and these projects will provide a higher bandwidth wireless Internet solution.

Based on our Wireless research we believe the best solution at this time is a Wireless/RF LAN utilizing PCMCIA cards in our wearable PC's (Figure 7) with access points/hubs (Figure 8) to extend the range from the aircraft to the server in the hangar. We are currently the technical point of contact for an SBIR to research and potentially develop a low power RF PCMCIA card. Specific technical requirements include a bandwidth greater than 10Mbps with encryption and LPI (low probability of Intercept) over ranges approaching 2800 feet.

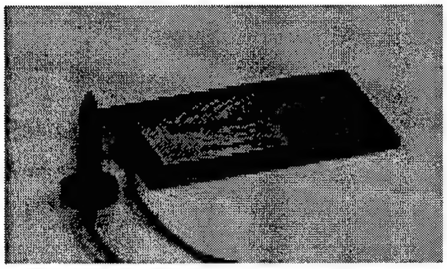


Figure 7
Proxim RangeLan2

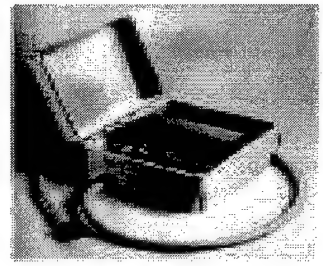


Figure 8
Proxim Outdoor AP Enclosure

The recently approved IEEE 802.11 specification which was meant to provide interoperability for Wireless LAN's, will certainly be a springboard to Vendors such as Lucent, Proxim, and Aironet to develop Wireless COTS hardware that will meet our bandwidth requirements. Unfortunately, Lucent and Aironet are promoting the 802.11 compliant Direct Spread Spectrum (DSSS) technology, which will attain 10 to 11Mbps. However, Proxim, is following the European HiperLAN specification, which can provide up to 23Mbps throughput and international usability. Although, the 23Mbps-bandwidth figure is inviting, will the HiperLAN specification be adopted in the United States or will DSSS technology prove to be the standard.

F. Wearable Color Video Camera

A key portion of the wearable concept is the ability to receive expert help through the Internet. Specifically the user would have a microphone and micro video camera to communicate/show the avionics problem that needs expert help/attention. We are currently researching camera's that will provide suitable wireless LAN integration with full duplex audio (voice) to provide a Tele-video/conference capability. We have been very successful in utilizing inexpensive (under $200) camera's to send video over a wireless network. However, when an additional task or when an additional user utilizes the same wireless network, it is clear that additional bandwidth is required. In addition, we must coordinate the usage of the sound card between the video teleconferencing and the voice recognition engine so that the system continues to be hands-free during the teleconferencing. We are not aware of any combination of speech engine and teleconferencing software that presently provides this functionality.

G. Extreme Temperature Environments

Navy Aircraft are stationed throughout the world and face a wide range of severe environmental conditions. The wearable would be required to operate below zero degrees Centigrade to +50 degrees Centigrade. To meet the Navy's mission, wearable electronics will need to operate in these extreme conditions without failures dues to overheating or an inability to

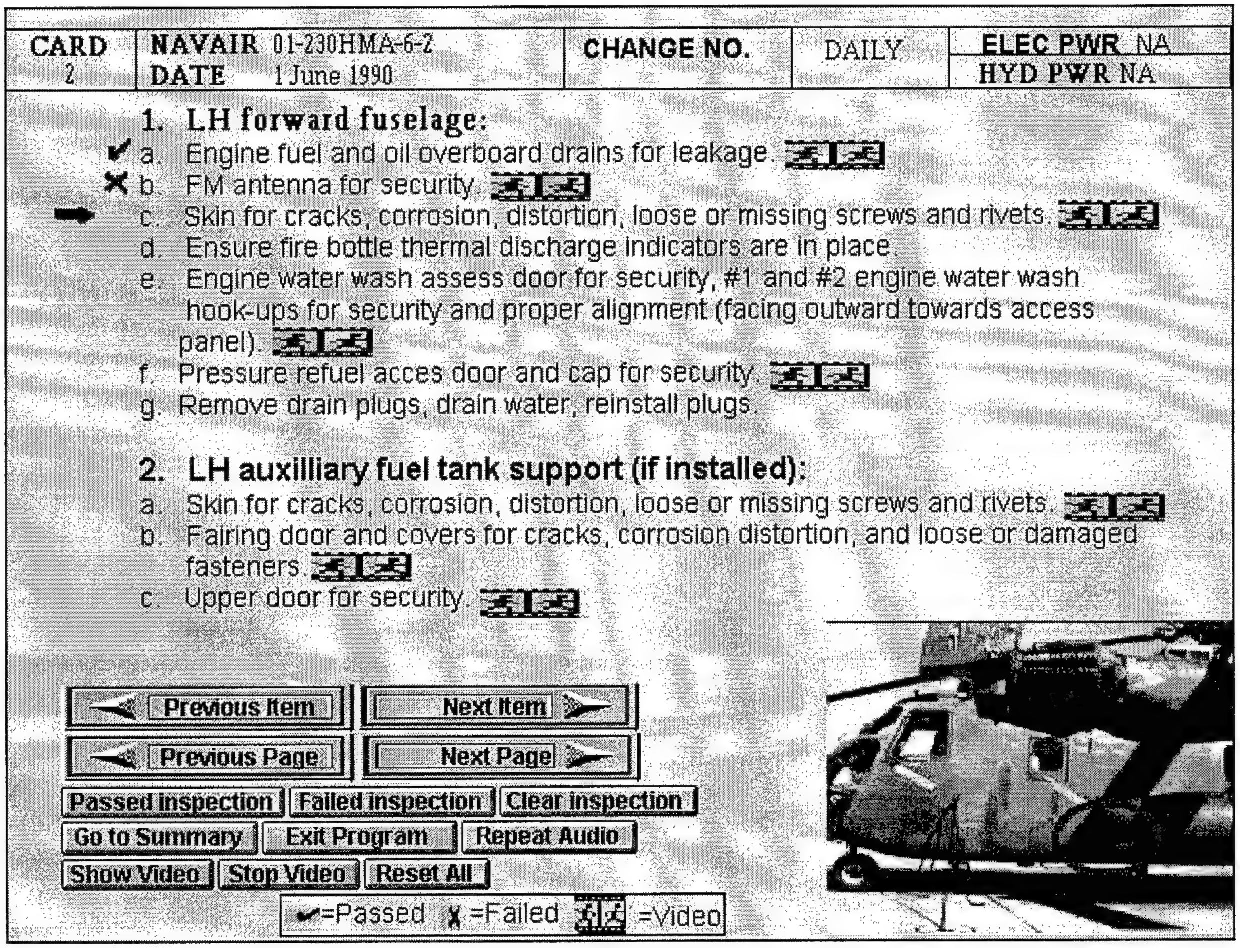
perform in conditions below freezing. At this point no wearable on the market today meets these requirements. In speaking with wearable manufacturers, they believe external devices to heat or cool the wearable would be the most cost-effective method to meet our requirements.

VI. Demonstration Programs

A. Phase I

We have utilized the Quest Multimedia Toolkit, from Allen Communications, to develop a sample electronic MRC application. The Quest toolkit allows for rapid drag and drop development of interactive multimedia based applications without the need for advanced programming skills.

We then utilized the Microsoft Speech Application Programming Interface (SAPI) to develop a custom program utilizing the C++ language to allow for voice control of the electronic MRC. The Phase I demonstration proved the feasibility of a speaker independent voice controlled electronic MRC with built-in recording of pass/fail statistics and tracking of tasks that were not performed by the AMT. Figure 9 shows an example of an electronic MRC. The demonstration was basically a standalone application, not developed to be incorporated in a client-server-networking environment.



B. Phase II

Our Phase II demonstration, presently under development, is being designed for Internet and client-server compatibility. Specifically, we are utilizing Active Server Pages, with Visual Basic scripting, to build web pages that properly display MRC information that is stored in an MS Access database.

The Microsoft Internet Explorer, with embedded Active X voice recognition software, will be used to display the electronic MRC web pages.

The wearable PC user will utilize an Internet browser to request information from a server in the same way we surf the web, with the enhancement of voice control.

VII. The Future

We are extremely excited about the future of wearables within the DoD, corporations and in our private lives. It is a certainty that wearable PC's will continue to shrink in size and weight, and they will also drop in price as chip prices decrease and as the wearable market

increases. The Seiko Corporation has just introduced a watch in Japan that is being marketed as the first wearable PC. While one could argue this point, since it has limited abilities compared to the Mentis, Xybernaut and Via wearables that have been on the market the past two years, it is the first wearable PC marketed to the general public.

As we discussed above, there are many challenges ahead of us, however we believe the wearable will meet DoD's needs regarding Avionics Maintenance and many other areas where a truly personal computer would help to increase communications, accuracy and productivity.

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Re-Engineering Paper Technical Manual's Troubleshooting Procedures

Dr. Li Pi Su, Advanced Technology Office
The US Army Test, Measurement, Diagnostic Equipment Activity
The US Army Aviation and Missile Command, Redstone Arsenal, AL 35898
Ms. Mary Nolan, Giordano Automation Corp. Sparta, NJ 07871

Abstract -- As the Department of Defense (DOD) downsizes there is a great need to reduce the cost and manpower burden associated with maintenance of weapon systems. Traditionally, technical manuals used for field maintenance of DOD systems have relied heavily on troubleshooting procedures, which are presented in "flow chart" format of fault trees. These flow charts guide the maintainer through test procedures to isolate parts that cause equipment malfunction. These procedures are static, that is, they are highly structured around a predetermined sequence of tests, do not become "smarter" over time with historical maintenance data, and only take into account those symptoms and faults which the original developer considered. They are often incomplete, sometimes wrong, and are very difficult to update and maintain. As maintenance evolved into the computer-assisted age, a major opportunity exists to significantly enhance the technical manuals, the basic logic, and information/knowledge representation underlying troubleshooting procedures.. This paper provides the high lights of research and development results on the technical aspects as how to efficiently transition from flow-chart intensive knowledge representation to a knowledge-based system. The results of reengineering the legacy trouble-shooting procedures provides, at least, the following benefits: (1) replacing fault trees with knowledge based reasoning about faults related to symptoms; (2) providing the capability to dynamically relate faults to symptoms; (3) equipping the ability to use historical maintenance data to continuously improve maintenance capability; (4) providing more user-friendly interactive electronic technical manuals; and (5) providing the ability to house "expert" diagnostics information in a form that becomes usable and available to novice technicians.

I. INTRODUCTION

Currently, field maintenance of Department of Defense (DOD) weapon systems relies heavily on troubleshooting procedures (TPs). However, these TPs are in a "flow chart" format of fault trees. The TPs are static, that is, they are highly structured around a predetermined sequence of tests and they do not grow smarter over time with the use of maintenance historical data. Moreover, the TPs are sometimes incomplete and/or inaccurate in performing diagnostics. The TPs are also cumbersome and poorly integrated with embedded test and automated test procedures. These factors result in a significant maintenance burden for the DOD.

To cope with the DOD's shrinking budget and downsizing, reengineering TPs to reduce this maintenance burden is a must.

The Advanced Technology Office (ATO), U.S. Army Test, Measurement, Diagnostic Equipment Activity (USATA), U.S. Army Aviation and Missile Command, initiated a research and development (R&D) effort to reengineer the TPs in 1995. In December 1996, the ATO

teamed up with the Logistics Support Engineering Directorate, ARDEC and Giordano Automation Corporation (GAC) to investigate and develop an enhancement methodology for reengineering the technical manual's TPs. This paper provides some of the key results of our efforts.

II. ISSUES WITH TPs AND TECHNICAL MANUALS (TMs)

In general, the TPs contained within TMs have following issues that make them noneffective and result in a big maintenance burden:

A. Most troubleshooting logic is represented in flow-chart format of "Fault Tree". The troubleshooting logic flows as follows: The results of one test leads to execution of the next test, whose result in turn, leads again to the next test. In short, the sequence of tests are predetermined and inflexible.

B. Fault trees are developed as part of the TM development process and are based upon a specified set of fault conditions. They are static, that is, they do not adapt to new or unplanned fault modes and they do not improve over time, based upon field experience.

C. Fault trees' static logic is limited to a "single fault assumption" and in multiple fault situations, can become very unreliable. This results in incomplete and/or inaccurate in diagnosing.

D. The TPs and TMs are often very cumbersome and poorly integrated with embedded test and automated test procedures. This results in ineffective maintenance or no maintenance solution.

III. ENHANCEMENT GOAL

The goal of this R&D efforts is to significantly improve the TPs and TMs to reduce mean-time-to repair, maintenance training requirements, and maintenance costs. For field diagnostics, the goal is to reengineer static TPs into a much more robust, simpler, and dynamic fault isolation mechanism. For the TMs, integration with embedded test and automated test procedures must be enhanced be more interactive and user-friendly.

IV. TECHNICAL APPROACHES

To accomplish the goal, a new paradigm of diagnostics reasoning technology is required that has the capability to eliminate complex diagnostic logic paths and the capability of receiving and dynamically interpreting any test results from any source, in any order, and with as many or as few test results at a time [2,3,4,5]. Moreover, an Interactive Electronic Technical Manual (IETM) authoring and display system must be robust and be able to integrate the diagnostics logic, the test procedures and routines, and technical manual information to provide a truly interactive interface between users, systems, test resources, and maintenance functions [6].

For these purposes, the technical approach requires, firstly, a diagnostics mechanism wherein **diagnostics logic is an entity independent of test procedures and routines, that is able to dynamically interpret test results,** and whose **diagnostics logic can be recaptured from legacy TPs and other data from TMs**.

Secondly, it requires an **overall object-oriented structure and an open architecture.** The concept of object-oriented programs enable taking full advantage of dealing with the diagnostic logic as an entity independent of test procedures and routines. The independent diagnostic logic contained in the software object can be rehosted to any platform without any problem, because it is simply a software object - such as a binary file [4,5].

Thirdly, it also requires an IETM authoring and display package, which is CALS-compliant and also highly robust. This authoring system must be able to integrate the diagnostics logic, the test procedures and routines, technical manual information, and other required maintenance information to provide truly interactive and full complement of dialogs.

In looking for a new paradigm of diagnostics technology satisfying above requirements, **Diagnostician** was identified. The **Diagnostician** is a greatly enhanced model-based diagnostic reasoning system that is significantly enhanced from DARTS, a concept/technology developed by the ATO, USATA, and GAC during 1992-1993 [1] and commercialized by the GAC. The **Diagnostician**'s model-based diagnostic software is used in an object-oriented software environment - the diagnostics logic is an independent entity that is able to dynamically interpret test results. The basic knowledge used by the **Diagnostician** includes a fault propagation model that maps all possible faults to all possible symptoms (tests or visual observations). Normally, the basis for this mapping is derived (automatically translated) from computer aided design (CAD) data (netlists describing, hierarchy, interconnectivity, components and pins, and signal flow).

The **Diagnostician**'s knowledge bases, called a fault/symptom matrix, is a model in the form of a connectivity matrix that represents the propagation of faults (rows in the matrix) to observable

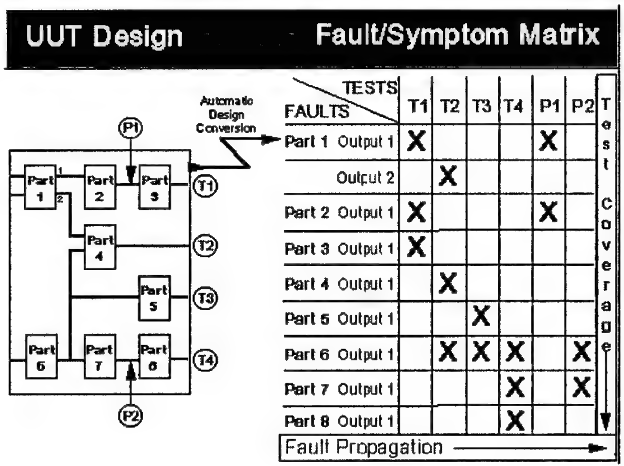

Figure 1

measurement locations and the coverage of tests that Pass or Fail (columns in the matrix). (See Figure 1). When used in run-time, the **Diagnostician**'s algorithms and knowledge bases (matrix) operate to isolate fault without troubleshooting sequences and without hard-code diagnostic logic.

To identify the required IETM authoring system, a study was conducted by the ATO over four authoring systems. A chapter of a paper technical manual was selected and converted into an IETM using each authoring tool. This was done to evaluate the features of each tool [6]. Sixteen different features of these authoring tools were investigated. These features include spell checking, animation, audio, video, execution of external programs, implementation of hotkeys for voice actuation, ease of linking frames, hotlinks capabilities, flexibility, whether or not a standardized format is required, whether the authored text requires compilation before viewing, graphics requirements, Object Linking and Embedding, cost, provisions for DCA, J1708, J4 and 1553 connections and interfacing and the troubleshooting capabilities of the IETMs.

The Raytheon (formerly Hughes) "Advanced Integrated Maintenance Support System (AIMSS)" IETM authoring and display system was identified to be the best IETM authoring system for this development effort. The AIMSS is a CALS-compliant and Class IV SGML IETM system. The AIMSS uses overall object-oriented structure and is an open architecture approach. It can integrate the overall IETM with diagnostics logic, test procedures and routines, technical manual information, and other requirements. AIMSS uses a common graphical user interface to display maintenance information in text, graphics, and table windows that can be easily manipulated by the technician for preferred viewing. Hypertext and graphic "hot spots" are embedded in descriptions and procedures to provide rapid access to related information contained in the database.

V. REENGINEERING PROCESS

The objective of the R&D efforts is to identify/develop a methodology/process to significantly improve the TPs and TMs to reduce mean-time-to repair, maintenance training requirements, and to reduce maintenance costs. As mentioned above, the **Diagnostician** will enhance legacy TPs by using dynamics model-based reasoning. Normally, the **Diagnostician**'s diagnostics knowledge bases are derived from the systems' design information. For legacy systems, the paper TMs and their TPs are the primary source of information that pertains to diagnostics. The issue now is how to cost-effectively reengineer the TPs into dynamic knowledge bases for use with the **Diagnostician**. The solution is to implement the following three steps cost effectively: (1) **Capture Diagnostics Logic from Paper TMs**; (2) **Reengineer Test Ordering Constraints and Information**; and (3) **Seemlessly Integrate Experiences into Model Based Diagnoses.**

A. Capture Diagnostics Logic from Paper TMs

Normally, and optimally, the diagnostic knowledge base is automatically generated from CAD output files, or netlists. A primary benefit of **Diagnostician** is its model-based diagnostics approach--a design-derived knowledge base that is a one-for-one *representation* of the design. That is, the direct relationship between design and fault propagation. For legacy TMs, this does not exist and even the netlist data may not exist. Therefore, alternate means for data import are required to reconstruct the relationships between symptoms and faults. In reengineering TMs' TPs, the best we can hope to accomplish, initially, is to generate a diagnostic representation that is as good as the existing TPs, because data is limited and we must assume that further information is unavailable. Note that a fault tree is an *interpretation,* and the reengineering of that fault tree into a knowledge base is a further interpretation of that interpretation.

There are four alternatives to capture legacy diagnostic data. The users can use any one or more to cost-effectively capture the diagnostic data.

1. **Capture SGML Tagged Data** - Automated software routines were written to extract diagnostic logic from SGML tagged data. The Army's 2361 DTD was analyzed with respect to data content of troubleshooting logic. A standard format was developed that allows conversion tools to be tailorable to other DTDs, since the basic content is expected to be the same.

2. **Capture From Paper-Based Troubleshooting Trees** - A reengineering methodology and supporting tools have been developed to analyze the fault tree structure representation of TPs and represent that tree structure in a knowledge base format. The reengineering methodology includes generating the diagnostic model, defining each test procedure, and incorporating the test path to each fault using the tools inside the Diagnostic Profiler.

3. **Capture from an "Expert"** - If an engineer or technician having expertise on the system

application is available, that expert can create the diagnostic model by directly authoring the fault conditions and correlating the test results or symptoms to those fault conditions (define how tests "cover" faults).

4. **Capture from Schematic Data** - If detailed schematic data is available, as well as knowledge on test coverage, the user can use a schematic capture program, such as OrCAD, to enter schematics and output EDIF netlist files. These files can be directly imported to the Diagnostic Profiler.

B. Reengineer Test Ordering Constraints and Information

In most TPs, test sequences are predetermined by fault tree structures. The tree structures represent the results of an analysis rather than the underlying information from which they were generated.

During the R&D efforts, it was determined that additional test ordering services must be added to the Diagnostician to make it truly serviceable for reengineering legacy TMs' TPs. Two factors that provide overriding test order constraints are (1) the impossibility of implementing tests under certain circumstances (e.g., measuring a frequency on a signal with no amplitude or checking a powerless display for fault codes), and (2) the need to use tests to step a unit under test through each of its states (e.g., power up, set mode, start function, handle error, etc.) especially when stepping from one state to another takes a relatively long time.

Based on these findings, a set of conditions and associated constraints or actions was developed to be used in generating tests dynamically. Each test could have no conditions placed on it, conditions about the status of one or more tests placed on it, or conditions about the status of all the other tests placed on it. Test conditions and constraints include whether the test is *permitted* to be run, whether it is *prohibited* from being run and whether it is *forced* to be run based upon the outcome of previously run tests.

C. Seemlessly Integrate Experience Data into the Model Based Diagnostics

Now, the legacy TPs have been reengineered into model based diagnostic logic, inferences are structured in an object-oriented, database-type software architecture, and the underlying data can be easily improved and updated over time. With these enhancements, run-time diagnostics can be "smartened" by incorporating field information into appropriated diagnostic reasoning. There are many useful data sources and situations that can smarten diagnoses: Frequency of Parts' Failures; Failure Modes; New or Unforeseen/Un-Modeled Failure Modes; New or Unforeseen/ Un-Profiled Test Data; and Mismatches in Diagnostic Knowledge Base (DKB) based on Incorrect Design Data Modeling and/or Test Coverage Input, etc.

To make the best use of the historical/field data mentioned above, the overall implementation strategy is to collect data on a local basis and allow this local data to be automatically

incorporated into the diagnostic reasoning process for current/local diagnostic sessions. The experience data, all local history, would be collected and processed/coordinated by a central facility. The historical data would be analyzed with automated tools and the system DKB would be updated accordingly. Then, processed/coordinated data will be redistributed to each using site.

The refinement and maturation of the DKB can be performed as follows:

1. **Frequency of Parts' Failures and Failure Modes (Failure Probability Updates)** - The DKB contains relative failure rate information that is used to determine the most probable cause of a set of symptoms. For diagnostic sessions where there is an ambiguity group, failure probability data is used to weigh the most probable suspect.

A "Run-time Smartener (RTS)" has been developed to incorporate failure rate data from actual field experience. The RTS utilizes the original failure rate data as initial Bayesian probabilities and updates these probabilities from a log file each time that a repair has been identified to correct a problem. User input has been minimized.

To implement the RTS, a Fault History Database is extracted from the historical maintenance records/database, or directly from Diagnostician data logging mechanisms. At the local level, mechanisms have been incorporated to the Diagnostician to automatically update fault probability data based on the field experience indicated by a Fault History Database. This is accomplished through a secondary file containing updated probability data. Incorporation of these updates into the primary DKB is performed at the centralized maintenance activity. The updated DKB is then distributed to local users.

2. **New or Unforeseen/Un-modeled Failure Modes** - To improve diagnoseability for the new or unforeseen/un-modeled failure modes, an Observable History Database (OHD) is created. An OHD is a database that contains any faults that were unaccounted for by the DKB in a maintenance session. It is extracted from the historical maintenance records/database as a secondary file accessed by the Diagnostician during a diagnostic session. The OHD would reflect that fault mode. The symptoms that were observed or tests that were measured will be noted and the knowledge base structure filled in accordingly. The fault data would be denoted as a learned mode. Certain symptom data may need to be noted as "masked" for uncertain test data. For these learned modes, in some cases, it may not be appropriate to use pass data to eliminate a fault mode in the reasoning process, since the confidence in the test coverage data is more uncertain (not physically tied to the model.) If this is so, only fail test data is used for reasoning, not pass. Some sort of a confidence level should be attributable to the learned fault mode.

3. **New or Unforeseen/Un-Profiled Test Data (Observables)** - The fault/symptom matrix columns represent coverage of specific tests' measurements. When new or unforeseen/un-profiled test data occurs, the fault/symptom matrix columns will be updated to reflect fault/symptom matrix, and hence, the diagnoses. If a test fails, the potential faults, which could have caused the test to fail, are identified vertically down the column. If new test data becomes

available, or observable, and can be related to a specific fault or set of fault possibilities, then a secondary file can be created/updated which denotes a new column in the matrix. The new column would be identified as a learned or added column. Certainty levels should be added to the possible faults associated with the learned columns. These certainty levels would be different from the fault probability data.

4. **Mismatches in DKB based on Incorrect Design Data Modeling and/or Test Coverage Input** - In some cases, historical data may identify situations where the DKB is wrong based upon design information related to fault propagation flow. This would result in wrong items being indicted based upon test results. Either the fault call-out excludes items, which are possibly faulty or includes items, which are fault-free. This would have occurred from incorrect design input data, which reflected the signal flow connection improperly. The case to be fixed in this situation is where an item, which causes the fault, is not included in the ambiguity group.

VI. DIAGNOSTICS DRIVEN IETM INTEGRATION

The objective of using AIMSS IETM authoring and display package is to develop diagnostics driven IETM. This IETM provides the user with the capability to display maintenance information in text, graphics, and table windows that can be easily manipulated by the technician for preferred viewing. Hypertext and graphic "hot spots" are embedded in descriptions and procedures to provide rapid access to related information contained in the database. For example, while viewing a fault isolation procedure, the technician is provided direct access to related information such as schematics and parts lists via links that are embedded in the text of the procedure and its associated graphics. The AIMSS, a truly interactive authoring system, supports a full complement of dialogs and processes that can be embedded in interactive procedures.

In the Windows environment, the Diagnostician inference engine is a Dynamic Link Library (DLL). It is structured as a library of functions that provide diagnostic services to a client program. Using the AIMSS IETM authoring tool, the Diagnostician's DLL functions were integrated through the Process Editor as "Class V" processes. The "Class V" process acts as a "gateway" to all Diagnostician services. Each "Class V" process interacts with the Diagnostician using Templates. Each template defines a DLL function. Templates are easy to use, provide the function call's exact syntax requirements, and simply require the user to identify specific variables, where applicable.

The Diagnostician contains about forty DLL functions. Of those, the primary ones that will be used for a typical diagnostics driven IETM application are as follows:

Load DKB	Load a System's Diagnostic Knowledge Base
AddData	Input test results to the Diagnostician

GetNextStep	Identify next step to be performed (normally, a test procedure)
GetSuspectCnt	Identify the number replaceable items in the current fault call-out
GetSuspectNames	Identify the name(s) of the replaceable items in the fault call-out
LogData	Log all session history data into the historical data base
EndSession	End the current diagnostic session.

With these basic functions, the diagnostic logic that is authored into the IETM is one "WHILE" loop. The WHILE loop processes as shown in the graphic below. No matter how large the system, or how complex the diagnostic logic, this single WHILE loop (see Figure 2) is all that is needed to incorporate the diagnostic processing with the Diagnostician.

VII. BENEFITS OF REENGINEERING TROUBLESHOOTING PROCEDURES

The objective of this effort was to reduce the maintenance burden of DOD weapon systems by reengineering static TPs of legacy TMs. The objective was achieved with the following benefits:

A. Troubleshooting Procedures replaced by dynamic and more robust diagnostics capability

Diagnostician provides dynamic diagnostic reasoning, instead of static troubleshooting trees. During a maintenance session, the test results can be input to the Diagnostician in any order (no preset sequence) and from any source individually or in combination (including operator observations, test instruments, data bus, data file, built-in test (BIT), automatic test equipment, system panels displays, etc.). Test results can be input as many or as few at a time as the test source(s) can provide (not restricted to one-at-a-time to traverse down a fault tree). The Diagnostician zeroes-in on causes of fault(s) and never

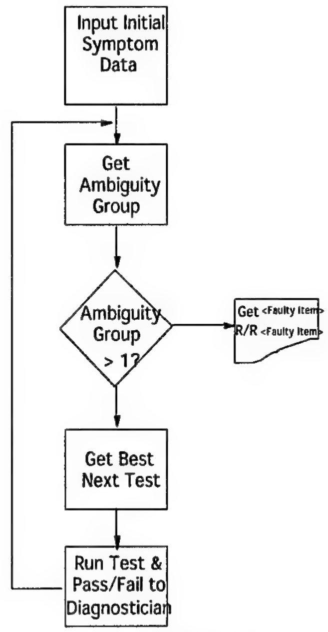

Figure 2

leaves the technician hanging in the middle of a tree! The Diagnostician can identify multiple faults (diagnostic trees follow single-fault assumption). The Diagnostician will only request tests that have diagnostic significance, based upon snapshot of current fault possibilities, and therefore, may decrease overall repair time and increase diagnostics accuracy.

B. Capability of Using Historical Maintenance Data to Continuously Improve Diagnostic

Data Logging of Maintenance History was defined for continuous system diagnostic learning. The Diagnostician creates a log of session profiles. This log is used by the RTS utility to mature diagnostic capability over time. The RTS performs statistical analysis on session history data to identify trends and actual field failure rate data. This is used to automatically or semi-automatically update the DKB and provide improved diagnostics.

C. Built-in Test Data are used for maintenance

Most BIT is designed to support operations, not maintenance, because it focuses on fault detection at the functional level as opposed to diagnostics at the replaceable item level. The Diagnostician can interpret any BIT data and correlate BIT results to a component/item-oriented model of the system. It therefore extends BIT into a maintenance mode to enhance field diagnostics and maintenance.

D. Class V Diagnostics driven IETMs vs. paper TMs

A much more user-friendly IETMs capability was developed, providing the capability to house "expert" diagnostics information in a form that becomes usable and available to novice technicians.

The following are additional benefits for IETM developers:

E. IETM Authoring of Diagnostics is Greatly Simplified

Authors are not required to author the complex "IF THEN...GOTO" logic associated with structured diagnostic trees - all diagnostic logic is inside the DKB. The author simply creates one WHILE loop to manage the dialog with the Diagnostician.

F. Possible Elimination of SGML tag the troubleshooting logic

SGML tagging for diagnostics is very complex and requires extensive content tagging. This can be eliminated by creating the DKB from design data or from an engineering analysis of the troubleshooting trees directly.

VIII. CONCLUSION/SUMMARY

The R&D project to create the capability of reengineering troubleshooting procedures into dynamic model-based diagnostics was successfully completed. The new paradigm for diagnostics, the Diagnostician and the AIMSS IETM authoring and display package worked together very efficiently to accomplish the reengineering task. The troubleshooting procedures from TM for the Army's Fox NBC Reconnaissance vehicle was used as a testbed. A diagnostics driven IETM was successfully completed for Fox. The maintenance school is using it as a training tool. This methodology to reengineer troubleshooting procedures in TMs is generic and can be reused for other legacy systems both from DOD and commercial industry.

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Biographical Sketch

Dr. Li Pi Su has a B.S. in mathematics, Taiwan Normal University, Taipei, Taiwan, 1959; Ph.D. mathematics, University of British Columbia, Vancouver, Canada, 1966; and B.S. electrical engineering, University of Oklahoma, Norman, Oklahoma, 1983. 1966-67, Post Doctoral Research, University of Toronto. 1967-68, Professor of Mathematics, Tsing-Hua University, Taiwan. 1968-78, Professor of Mathematics, University of Oklahoma. 1980-85, Electrical Engineer, Department of the Air Force (Tinker AFB, OK). 1985-92, Logistics Engineer, Department of the Army (Lexington Army Depot, KY). 1992-Present, Electronic Engineer, Software Engineering Division, U.S. Army, Test, Measurement, and Diagnostic Equipment Activity, Department of the Army (Redstone Arsenal, AL). Since 1992, she has completed management of the research and development projects: the Diagnostic Analysis and Repair Tool Set; Embedded Diagnostics; Reengineering; the Integrated Diagnostics; and Repair Information System Programs. She also has been researching and developing diagnostics/prognostics technology and Interactive Electronic Technical Manual related technology.

Ms. Mary Nolan, Vice President of Systems for Giordano Automation Corp. since 1991, is responsible for applications of the company's diagnostics tools, the Diagnostic Profiler and Diagnostician. She was a Senior Systems Analyst of Giordano Associates, Inc., during 1981-1991. Ms. Nolan has a BS Degree from Trenton State College and also attended the Defense Systems Management College Program Managers Course in Ft. Belvior. Since 1981, she has been working on research and development of automated test and diagnostics, integrated diagnostics, embedded diagnostics, and related areas. She has participated in definition, development, application, and support of an advanced concurrent engineering implementation methodology and associated tools and that facilitates the automation of the "design-to-support" aspect of integrated product development. That resulted in an Expert System Application that provides diagnostic capability at a significantly reduced development and O& S costs. Among many implementations she did on enhancing design for testability and diagnoseability, she participated in the development of MIL-STD-2165. She defined, managed, and participated in implementation of the Diagnostician in several testers at San Antonio Air Logistics Center for Depot Support of F-15 and F-16 repairables. Currently, she is also working on reengineering the troubleshooting procedures from legacy technical manuals into model-based diagnostics driven Interactive Electronic Technical Manuals.

Dynamic Autonomous Test Systems for Prognostic Health Management

Presenter: **Kenneth G. Blemel, Management Sciences, Inc.**

Track:

Abstract

This paper presents the state of the art in real time reactive supervision using micro-module sensors. The paper will show how automatic test equipment is becoming more and more an anachronism as the Joint Strike Fighter Prognostic Health Management (PHM) team forges new links that connect on-board, event based diagnostics and prognostics to ground-based support. The paper will discuss how on-aircraft PHM combines micro electro-mechanical systems (MEMS) and micro-electro-optical systems (MEOS) with prognostic microprocessors to sense, detect, consider, prognose, message and perhaps correct problems. The paper will explain how miniature electronic technology (E.T.) will use web based JAVA technology to receive rules for PHM and send results of PHM via downlink to the Joint Distributed Information System. (JDIS) The paper will show how E.T. is embedded in the wiring, cables and connectors that are the life lines of the electronic systems, and how E.T. will be fused into mechanical structures to detect aging and battle damage. Finally, the paper will describe the cost benefits that result from radically changing the current way defense systems are supported.

1.0 The Problem with Test Equipment

Test equipment and test software program sets have come a long way in the past fifty years. In the 1950's test procedures often were done with a voltmeter and eight weeks of training in basic electronics. The transistor changed the picture. In the 60's and 70's test sets were developed to check the combination of analog signals and digital "1's and O's" used in avionics and other systems. In the 80's computer programs entered the picture, adding complexity. "Can Not Duplicate" and "Tests-OK" now represent about 50% of test results. Maintenance personnel spend about ten times longer trying to "fix" these problems and often introduce a fault just to reduce the trouble. "Cannot Duplicate" (CND) and "Tests OK" (TOK) situations represent about 50% of today's repair results. CND and TOK are frustrating, and many operators just ignore the fault indications and hope its another "false alarm". Test equipment from the days of TTL logic and circuit boards just cant cope with emerging massively parallel architectures used in defense systems. The complexity is just too great, such as testing the stealth characteristics of a fighter which must be done during flight.

History has shown that "false alarms" can make systems appear to be very unreliable, and can take several maintenance hours per flying hour. The F-15 electronic systems have a average "mean time between failure" of under 100 hours. The F-15 logs about 25 maintenance man hours per flying hour. Sortie rates are affected as the equipment is taken off line to be tested and repaired. The high altitude, high speed missions of other fighter aircraft like the F-16, F-14, and F-18 aircraft cause similar headaches. Other aircraft have similar situations, albeit of a lesser degree, as their roles are usually subsonic, and their environment for use is more benign. However, their test equipment problems are very similar. Developing and supporting test program sets is a big business dominated by a select few suppliers. Test sets come with their own problems, such as required use of ADA to assure software upgrades, and failure rates that are often as bad as the equipment being tested. The problem is getting worse as software begins to dominate the functionality of new systems. Testers designed to check voltage levels are not suitable for testing 400mhz computers used in digital signal processors and avionics today.

1.1 Cost Aspects

The cost of maintenance and support of current generation weapon systems usually exceeds the delivered cost. Test equipment costs are sky rocketing. It's not unusual for the cost of the ATE to exceed the half the cost of the product it is built to test. Spares, parts, TPS and ATE are very big business. The US Department of Defense spends about $8 billion on test related hardware each year.[1] Solving the problem of external test equipment is not a simple matter of spending more money.

1.2 The Added Trouble of Commercial Off the Shelf (COTS) Systems

The problem of cost and availability is not limited to the DoD. Commercial firms and businesses have many of the same problems. Commercial producers often produce only a few years of spares. Automotive firms have a three to five year spares policy. Many firms find that it is cheaper to scrap a failed computer or system than to try to find replacement parts. The DoD hopes to replace expensive custom systems with systems built from commercial off the shelf (COTS) components. But, most commercial off the shelf (COTS) components are not designed to be testable, and COTS products are usually not durable enough for harsh military environments. Also, COTS products are constantly upgraded and revised to add new technology. New systems will be increasingly complex.

2.0 The Joint Strike Fighter (JSF)

The JSF is a good case in point. Like the F-15, the JSF is a multi-role strike fighter aircraft. In the past, this meant that the JSF would contain about one hundred analog and digital "black boxes" performing dedicated functions. However, the JSF will be mainly "flying software" with numerous distributed computer systems that will share and participate in function. The JSF will be a "fly by light" supersonic aircraft with electronic "black boxes" running complex software. Having distributed processing provides redundancy and flexibility which mean increased survivability and inherent reliability. But inherent reliability only lasts until the first failure. Many failures will be software "glitches" that appear to be failures of hardware. Operational availability depends on the repairability and testability of the hardware and software. Unavailability will result if the test equipment designed for flying hardware is unable to cope with the new design architectures that replace prior generation

[1] Proceedings of the DoD Joint Test Conference, Orlando, FL, 1995

electronics with systems based on software signal processing. Untestability at the flight line will result in sending the equipment to repair depots and the manufacturers, inflating the pipeline and turn around time.

At the 1996 testability meeting for the JSF, test system and test software manufacturers said that the solution to having better testability only requires more time and more money, because better test sets will require better computer programs. But this means that the test modules are usually delivered long after the system enters service. Test equipment also fail, in two ways. They often fail to test the equipment they were designed for. And, the TPS/ATE components fail, requiring test sets for repairing the test sets. The Pentagon budgets for TPS and ATE represent a major part of new system acquisition costs and will rise dramatically if something is not done.

3.0 Solutions

Many system managers wait years to receive test program sets (TPS) and automatic test equipment (ATE) that simply do not perform as required because the test set programmers and developers can't cope with the complexity and changes. Faulty equipment gets recycled into the system to return again with great consistency. There are several feasible solutions to the problem: 1) allocate much more time and much more money to develop test program sets and ATE that will be able to cope with the complexity, or 2) increase the amount of self test and bit within the electronic systems. The advantages of spending more money on test equipment and test programmers are entirely in the pockets of conventional test equipment manufacturers and dedicated repair facilities.

There may not be enough time, or enough money to produce adequate test equipment and software. It is far easier to take advantage of the built in processing power and software diagnostics aboard the system. Real time diagnostics and tests performed aboard the system makes it possible to use prognostic health management. PHM diagnostic and prognostic procedures will provide detection and isolation services to make sure that only true hardware failures result in maintenance. The data generated by PHM will be delivered to the maintainers along with recommended procedures to assure a quick turn around. Figure 1 shows the principle elements of autonomous logistics support. Incidents aboard mission aircraft cause messages to flow to command and control centers of forward logistics support centers. Aircraft can be serviced at any facility having the skills and parts on hand, or the resources can be expressed to the selected support center.

3.1 JSF Prognostic Health Management (PHM) Office

The JSF program for PHM is managed by Dr. William Scheuren. The purpose of the project is to dramatically change the way aircraft and systems are designed, operated, maintained and supported. The JSF PHM office is promoting research and development of pro-active, built-in, on-board diagnostic and prognostic systems that will increase the safety, availability, performance, and affordability through innovations including use of advanced "smart systems" using sensor technology. The JSF PHM project wants real timely "Reactive Supervision" to observe, detect, reason, understand and react to ongoing events during missions, during maintenance, and throughout the life of the aircraft. The PHM will result in autonomous logistics support achieved through watching for symptoms, detecting problems, isolating faults, and performing real time repair/restarts. The PHM system will report to cockpit displays, hand held maintenance aids. Data links will transmit health and status information to support sites.

3.2 Short and Long Term Goals

The long term DoD/JSF goal is to eliminate ground support test equipment and test program software wherever possible by moving test and diagnostics on-board, using aircraft computer systems to detect, diagnose, and isolate failures. Another goal is to have the aircraft systems order parts and maintenance during the course of the mission to achieve "autonomous logistics support". Autonomous logistics would be like breathing is to humans, eliminating much of the delays that choke and limit operational availability. The DoD would like to eliminate scheduled maintenance by shifting to "on condition" maintenance as needed. The JSF program wants to use methods similar to those used by commercial aircraft systems developed for Lockheed Martin, Boeing and Airbus Industries. New commercial aircraft designs like use on-board diagnostic systems to notify ground crews of maintenance needed to restore airworthiness. If the parts are in a city other than the destination, the airline has time to get the parts delivered "just in time" to cut the time otherwise required to wait for parts.

4.0 Embedded Self Prognosis and Dynamic Resource Management

Achieving autonomous supportability will require innovations that use fuzzy logic and expert systems to "feel" events, detect failures, and prognose the need for parts and maintenance during flight. The self prognosing system will use the test data built into the software systems. The system will determine recurring patterns during mission operations that are impossible to find after the system has returned to base. The diagnostic software will assess the probable root causes for faults and failures relaying the information to ground crews along with work instructions.

In 1996, DARPA awarded a contract to explore in-flight embedded self prognosis (ESP) using new software and sensor techniques to identify problems and select the maintenance and repair methods. The research demonstrated that ESP is not only feasible, but demonstrated using ESP handling "sledgehammer" failures in distributed computing systems. The contract identified other innovations such as moving ESP on computers in "smart wiring" to create an aircraft neural backbone. MSI demonstrated that smart wiring can be used to detect, isolate, and perform other reasoning to perform dynamic resource management (DRM) autonomously.

5.0 Smart Technology for Autonomous Logistics Support

Smart technologies are emerging "just in time" to enable autonomous logistics support. "Smart" sensors will provide the data, information and knowledge required for "on condition" maintenance. The use of intelligent wiring will also eliminate many of the problems caused by frequent technology upgrades. Technology upgrades are a fact of life caused by technology advances every few years. For example, many JSF electronic systems will be digital signal processors (DSP) that replace prior generation radars and analog systems for navigation and control. Most DSP use numerous dedicated COTS computer processor systems. According to Moore's Law, computing technology changes every 18 months. (Many claim it is closer to nine months today.) This means that JSF systems will be constantly upgraded with new technology to fend off obsolescence.

6.0 Virtual Prototype Co-Design

To be really effective, "smart systems" for PHM need to be designed in, with "open system" techniques that allow room for planned technology upgrades. The Defense Advanced Research Project Agency (DARPA) has teamed with NASA to fund development of hardware and software concurrent design using virtual prototyping. Three dimension (3-D) computer aided design (CAD) programs already have the necessary power needed to create a virtual hardware prototype of the mechanical design. Chrysler Corporation has been advertising how they virtually prototype new car designs. The new car design is driven over virtual highways to identify areas for improvement that improve functionality, reliability, safety and maintainability. The Rapid Prototyping of Application Specific Signal Processors (RASSP) project started in 1993 to develop computer programs automatically from behavioral specifications. As a result, co-design is being used to identify how and where to place sensors that will provide the data for on-board real time diagnostics, and to automatically produce the diagnostic and prognostic software needed to eliminate off board test program sets.

7.0 Neural Circuits and Smart Test Modules

To be cost effective, the designers of reactive supervision must dramatically reduce the time and costs associated with writing software programs. This paper presents the state of the art in real time reactive supervision using neural circuits comprise of micro-computer modules equipped with micro-sensors. Neural circuits are not neural networks. Rather, neural circuits are collaborating computers that work together to optimize reliability, supportability, maintainability and safety as part of the on-board computer systems

Smart neural sensor test modules can be designed autonomously test the health status of not only electronic systems, but also the mechanical and structural systems. Sensors can be built with microcontrollers and diverse micro machined electro mechanical systems (MEMS) and micro optical sensors. The smart sensor will process the data using rules stored in a knowledge base. When the rules indicate, the smart sensors take appropriate actions in the form of messages or using D/A converters to make controlled changes. Smart test modules connect to higher level smart processors which diagnose and prognose, sending condensed information to ground based support.

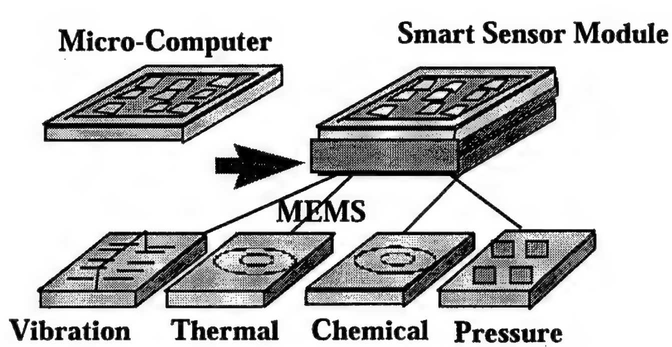

Figure 1. Smart Sensor Modules

8.0 Reactive Supervision

Rule bases used by sensory neural circuit modules can be used to detect when system elements need inspection, based on time since last failure, symptoms, exposure to ultra violet rays, temperature, vibration and corrosion. Rules can be established enabling autonomous activity to discover and correct problems. The nature of the reactive measures is defined in "fuzzy rules" loaded into memory. Smart sensors can take reactive supervisory measures defined in a supervisory program. The measures could be as simple as generating a message, or as complex as taking collaborative action in concert with several other smart sensor devices to regain control of situations.

9.0 Rule Based Autonomous Testability

Autonomous reactive supervision and dynamic resource management requires data inputs, rules, rule processing, recognition with discrimination, decision processes and taking actions. The rules define the sampling rate for the input signals. Rules also define the guidelines for reasoning processes. Java rules define the nature of any messages, commands or other actions using analog drivers. The smart sensors can attempt to take corrective measures, such as releasing chemicals to stop corrosion. Messages can be used to notify other Smart sensors or to notify maintenance personnel of problems such as loose connections or vibrations that cause chafing. If wiring is damaged due to fires or collateral damage, the smart sensors can switch to a better wiring configuration using cross bar switches. The rules used to detect the problems also provide the internet URL to receive the report of taking preventive actions. If desired, the receiving URL can request additional information, or request another configuration.

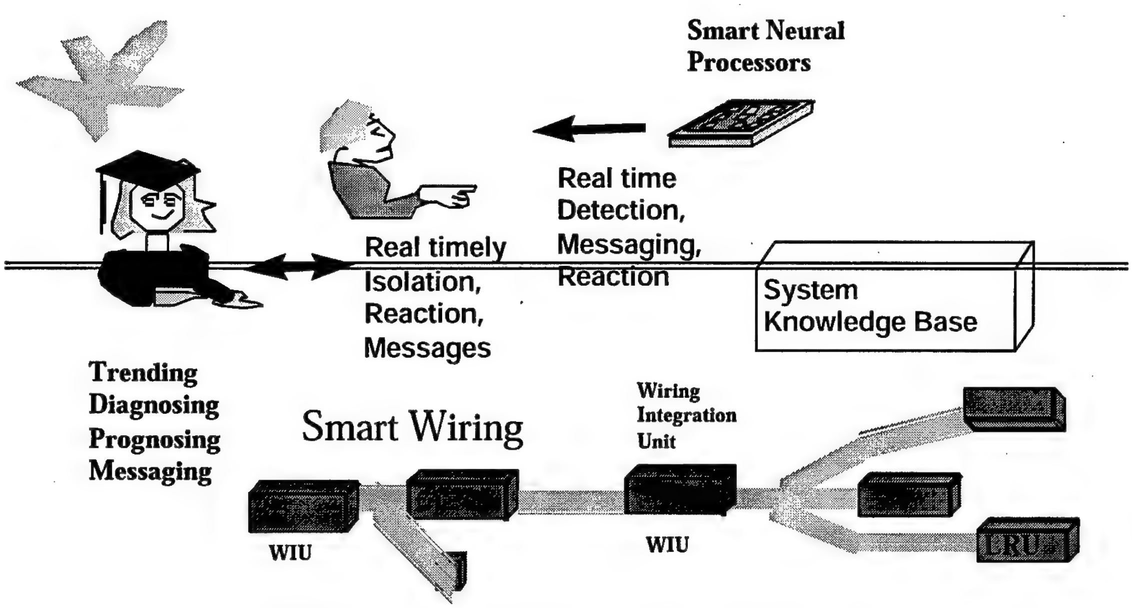

Figure 2. Autonomous Diagnostics and Test

10.0 Autonomous Logistics

On system failure isolation and verification also provides "autonomous logistics" which automatically order the parts and procedures from the support facilities where they are located. Autonomous logistics functions react immediately to gather the resources dynamically, unless overridden by human commands. Built in test information often can identify the root cause of the problem, such as a failure in the power supply. Economic decisions will identify the best way to restore operation of the system, and operation of the failed units.

11.0 "Smart" Wiring

Built in test information is too valuable to use only for maintenance. The data can be used by on-board processors to facilitate reassignment of assets to maintain functionality of mission critical systems. The wiring system that carries the test data information is an obvious choice for siting of PHM sensors and dynamic resource managers. By embedding computers and microcontrollers in the wiring, the electronics and software will be tested before, during use.

ESP in smart wiring can eliminate much of the ATE and TPS that would otherwise become expensive baggage. Demonstrations of the concepts were held in late May 1998. The JSF PHM program office has funded research projects to prove that smart wiring using COTS sensors embedded in COTS electronics and wiring is cost effective. Demonstrations are scheduled for late summer and early fall of 1998. On aircraft demonstrations are being scheduled for the summer of 1999. The latter demonstrations will show autonomous reactive supervision by on-board diagnostic and test systems embedded in the wiring system.

The advantages of using "smart wiring" are numerous:

- On-board restoration of many problems by rebooting, cold starts, or resets
- Accurate run time detection, diagnosis and isolation with on board computers
- Dramatic reductions in NFF and RTOK
- Significant reductions in maintenance
- Dramatic reductions in life cycle support costs
- Dramatic reductions in costs for TPS and ATE
- Substantial increases in operational availability and supportability
- Dynamic verification and validation of technology upgrades.

11.1 Applications for "Smart Wiring"

Wiring carry signals, power and data to and from processes attached to the wires. The wiring is very much like the veins and arteries of the human body. Current wiring systems are passive. Sensors can be added to the data network that are analogous to neurons that provide "feelings". The wiring is an ideal place to place the detection, reasoning, and reacting processors. Inventing a new generation of "smart wiring" starts with destroying most of the rules for conventional "dumb" wiring. Research to develop the "first generation of smart wiring" is being funded by the JSF PHM office. The project is getting enthusiastic support from DoD agencies who bear the cost and frustration associated with the current generation of wiring and test equipment.

11.2 Advantages and Benefits of Smart Wiring

Currently, most wiring is simply connections of wires from point to point. Wiring tends to work quite well until it is subjected to environmental and electrical forces that cause minute problems. Many problems take ten to fifty years to develop. The problems are usually related to chemical deterioration due to chemical reactions. When wiring begins to show signs of wear and tear, the problems that are generated can be very troublesome. In fact, most maintenance personnel would rather dig ditches than attempt to isolate problems in wiring harnesses. Current wiring systems are simply not designed for trouble shooting. In fact they seem to be designed to confound attempts to isolate problems.

12.0 Real Time Logistics Information Systems

In its long term vision, the DoD wants the ground support system and aircraft to autonomously reconfigure assets in order to complete missions. The DoD has initiated the Joint Distributed Information System (JDIS) network will be used to send information to the maintainers on exactly what is failed, identifying the maintenance procedure and parts that will be needed. In this way the support staff will have time to assemble the tools and parts needed to make quick repairs. On arrival, the maintainers will be better prepared to make repairs and quickly turn the system to fighting status. In peacetime, the failed units can be returned to the manufacturer for warranty support.

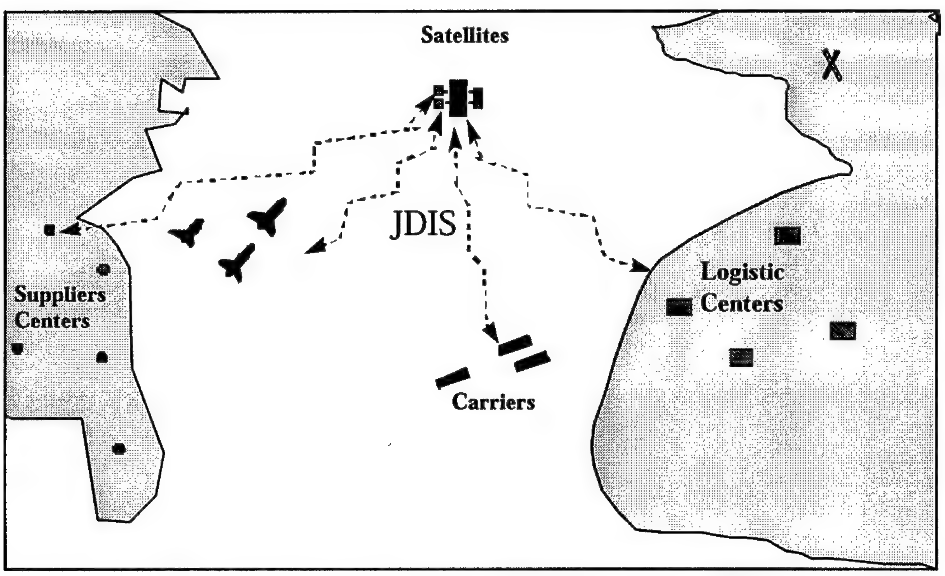

Figure 3. Autonomous Logistics using JDIS

13.0 Summary

The realities of shrinking defense budgets require massive changes in the way systems are designed, tested, maintained and supported. As a result of new initiatives, testability, availability, and supportability are changing. System managers, like Dr. William Scheuren of the Joint Strike Fighter PHM office are making significant efforts to reduce the cost and problems associated with test equipment, maintenance, and logistics support. Defense, automotive, and aerospace companies are designing new technology to bring diagnostic and test systems on board to enable having autonomous logistics support, higher mission availability, and dramatic reductions in external test equipment.

Using autocoding to develop test software will cut the time to develop test software by several orders of magnitude.

Practical Applications of Statistical Testing

S. Wayne Sherer
U.S. Army TACOM LCSEC

Gwendolyn H. Walton
Software Engineering Technology, Inc.

This paper describes the application of statistical testing based on usage models (i.e. using a statistical profile to select and generate test cases) to the Improved Mortar Ballistics Computer (IBMC), a next-generation system for aiming mortars in combat. The relationship between IMBC system specifications, usage models, and FQT scripts are described. Suggestions are given for tailoring the development and testing processes to facilitate the successful, cost-effective application of statistical testing to FQT.

Introduction

In statistical testing of software, a software usage model is developed to characterize a population of uses of the software (Figures 1 and 2). The structure of the model (states and arcs) describes the capabilities of the software. State transition probabilities represent a particular user and use. The key steps in developing a Markov chain usage model are described by [7]. The application of these ideas to the U.S. Army TACOM's IMBC project are described in later sections of this paper.

Because it is impossible to exhaustively test non-trivial software, it is important to determine the most efficient use of the test budget to satisfy the test objectives of the software life cycle. Mills [3] pointed out that testing with selected test cases can provide nothing but anecdotal evidence; statistical testing is needed to scientifically certify the reliability of software. The Testing Maturity Model [1] describes behavioral characteristics of organizations at five testing maturity model levels. In the model they state that at the highest testing maturity level, "usage modeling is used to perform statistical testing".

Statistical testing of software allows: modeling and quantitative analysis of software specifications, quantitative test planning and evaluation of test plans, and automatic generation of a statistically correct sample of test cases. Test management decisions can be based on scientific data that is computed before and during the test. The benefits of usage model-based statistical testing to support test planning, test generation, test automation, and software certification have been demonstrated in numerous industry and government software development projects and have been reported in various forums. For example: Texas Instruments described the benefits of applying statistical quality control principles to test embedded software [4], and the IBM laboratory in Tucson reported that statistical testing of software based on a usage model for mass storage device driver software "dramatically increases measurement opportunities both before and during the testing process" [9].
Despite the documented advantages of statistical testing based on usage models, many organizations are reluctant to consider a shift from traditional testing to statistical testing. We discuss one example of successful technology transfer to statistical testing at the U.S. Army TACOM.

Application of Statistical Testing to the IMBC

The Improved Mortar Ballistics Computer (IMBC), a next-generation system for aiming mortars in combat, consists of approximately 90,300 lines of Ada code developed using an incremental life cycle. The IMBC certification team was initially very reluctant to rely on statistical methods and a usage model-based sample to drive IMBC testing. There were a variety of reasons for their reluctance: it was a new certification team; the development project was using a new process [6]; the requirements continued to evolve during the specification and development work; and there were typical budget and schedule pressures. However, the project's management was committed to the application of statistical testing methods for this project, and, after some discussion, the certification team agreed to expend a significant portion of the IMBC testing effort on statistical testing.

Formal training in statistical testing was provided to the certification team members at the beginning of the IMBC project. During increment 5, some one-on-one training was provided for new team members. Because there was a 100% turnover in the certification team between increment 3 and increment 5, another formal training course in statistical testing was provided at the beginning of the increment 6 usage modeling effort. Coaching was provided on an "as needed" basis throughout the project. The CASE tool product, toolSET_Certify from Software Engineering Technology, Inc., was used to support usage modeling, test planning, test case generation, and statistical analysis of test results.

Some traditional testing and some statistical testing was performed on each IMBC increment. Statistical methods were used to predict a field reliability of 0.93 for the system as it existed at the end of increment 6.

IMBC Statistical Testing Activities and Issues

A defined process, training, coaching, and tool support were key contributors to the success of the IMBC project's adoption of statistical testing methods. Despite the turnover and associated learning curves, the certification team successfully applied some amount of statistical testing and some amount of traditional testing in each increment. The following gives brief highlights of some of the key activities and issues addressed during IMBC statistical testing.

Identify the test objectives and constraints

Because of constraints of evolving requirements and limited testing budget and schedule, a decision was made early in the project that it was not necessary to fully certify each increment. Each IMBC increment had a test objective to demonstrate that the development process for that increment was in control. Statistical methods were used in all increments for test planning and to generate test cases from a usage population defined by a usage model. Increments 5 and 6 were by far the most complex and included major parts of the functionality of the IMBC. Thus, more extensive testing was performed on the full system in increment 6. Statistical methods were used to predict the field reliability for IMBC as it existed at the end of increment 6. FQT was performed using traditional methods after increment 7.

Determine test environment and automation issues

Because the target platform for IMBC was unknown, testing was performed on a single-user DOS-based machine. Because testing was constrained to a DOS platform, test case execution and evaluation of correctness was done manually. Windows-based test capture and replay tools could have helped automate the IMBC testing process. Other projects [2, 4,5] have reported success in automating execution and evaluation of statistical tests. For IMBC, if automated test execution and evaluation were available, the resulting reduction in the time to run a test script could have supported (within the same test budget) statistical testing of more complete usage scenarios and more atypical scenarios.

Define test boundaries

The entire system was tested at the end of Increments 3, 6, and 7. New screens and modified screens were tested at the end of Increments 4 and 5. For software supplied and previously acceptance tested by another U.S. Army organization, only the interfaces were tested.

Define user, and use

Because the IMBC was designed with the capability of providing continual battlefield support, "invoke a use" and "terminate a use" in the IMBC did not have the same meanings as "invoke the software" and "terminate the software". Thus, some discussion was required before the team reached a consensus on the definition of use from which to develop usage models. For the purpose of statistical testing, the "user" of the IMBC was defined as a soldier in the field (either in training or in battle). A "single use" of the IMBC was defined as "performing one or more missions". "Invoke a use" was defined as initializing data for a mission (a new use may or may not build on data from previous uses). "Terminate a use" was defined as termination of a mission (with or without save) or completing a mission (may or may not have computed values for the mission).

Determine appropriate usage model strata

Possible usage strata were: fire solution versus non-fire solution, and type of mission (grid, shift, polar, or laser)

Develop and document usage model structure for each model

Despite the discussions to define "use" of the IMBC, because the certification team was inexperienced in usage modeling, it was difficult for them to consider the usage model structure from multiple views. However, given the complexity of the IMBC specification, multiple views were required to meet the testing objectives.

The IMBC GUI specification was screen-based. A usage model from the viewpoint of screen navigation was excellent for describing "what can we do at each screen" and was excellent for verifying completeness and consistency of the specification. Because a very long stimulus history

is required to define the probability of a particular transition, a screen-based usage model was less appropriate for describing usage scenarios that would be typical in the battlefield.

Typical IMBC system usage is highly modal because specific types of missions have very distinct characteristics, however, the IMBC software was not highly modal. It was designed to be very flexible and allowed many transitions between modes. This flexible design provided maximum flexibility to the soldier in use of the system and improved maintainability of the software. As is often the case, design flexibility brought an additional testing cost. One testing issue was caused by the fact that, like most non-modal software, the number of possible paths through the IBMC software was very large. A well-defined specification and development process including verification of the software prior to test mitigated some of the risk resulting from insufficient budget to test the possible paths. Another testing issue for IMBC was that "typical use" couldn't be accurately described with fixed probability distributions if the usage model was developed with each state representing a unique screen. A variety of usage modeling techniques were used to control the complexity of the usage modeling activity and to help the testing team deal with this issue. These techniques included the use of component modeling, state and arc abstraction, stratification of input data, and scenario-based usage stratification.

Determine transition probabilities for each model

Some transition probabilities were assigned based on testers' "best guess" from conversations with users of the predecessor system to IMBC. The remaining transition probabilities were assigned according to policies developed based on objectives and constraints of the testing for each increment using some of the techniques described in [8].

Process Benefits of IMBC Usage Modeling

The IMBC team realized the benefits of usage modeling as a specification activity very quickly. Because usage models were developed from the functional specification for the software, the usage modeling process provided valuable insights into the completeness and consistency of the functional specification for each increment of the IMBC project. This facilitated identification of specification problems before coding was completed.

The usage modeling process yielded artifacts that provided clear documentation of the certification team's interpretation of the system functionality. This greatly improved communication between the certification team and the specification and development teams.

By careful planning and the use of systems of component models, the certification team was able to realize significant reuse of usage models in each subsequent increment. This provided significant savings in model development and verification effort and made it easier for the certification team to tailor the model for each increment to meet the test objectives for that increment.

IMBC Formal Qualification Tests and Their Relationship to Statistical Tests

The objective of the IMBC Formal Qualification Tests (FQT) was to demonstrate that the IMBC correctly performed all the functionality included in the System Requirements Specification (SRS). A different team than the IMBC certification team performed FQT.

The IMBC SRS included natural language descriptions of requirements from the operational perspective. Specific data values to be tested were included in the SRS. After a small number of statistical tests were run on the full IMBC system after increment 7, FQT was performed using traditional methods to evaluate conformance of the IMBC software to the SRS. Although many more test sequences were run during FQT than during the statistical test of the system after increment 7, neither the statistical tests nor the FQT were extensive enough to be described as a statistically typical sample of any defined population of IMBC use.

After FQT was completed, FQT test scripts and test results were analyzed to determine the relationship between the FQT scripts and the usage models developed to drive the testing of each increment. The basic difference between the FQT test scripts and the usage models can best be described by the test objectives. The usage model structures were developed to exercise the functionality of the screens. Thus the granularity of the usage models tended to be close to uniform, and usage model scripts led the tester through each screen, giving indications for type of data to be entered but not specific values. For example two arcs in the usage model were "select existing Reg Pt" and "Press use all of valid data". The work to define the specific data to be entered during testing was done by the testing team outside the usage model. (This method of selecting test data after the test scripts was generated was the preference of the testing team. More detailed test planning based on the usage models could have yielded a more detailed model that included multiple arcs between states with stratified data values specified on the arcs.)

In contrast to the usage model scripts, the FQT scripts were developed to test specific data values for specific missions, specific weapons, and specific conditions. In general, the FQT scripts get the tester quickly to a specific screen, then give very specific instructions to the tester to loop through a series of screens multiple times, checking various specific combinations of data values.

For example, Figure 2 gives a high-level usage model structure that could be used to describe a subset of the IMBC software. In addition to the transition lines drawn in the figure, there are also possible transitions from every state back to "Main Menu" and from every state to "Terminate Use". An FQT script to exercise Fire Data with three sets of data might be of the form (where "Ö" represents the details of data entry for that screen):"Use Not Invoked, Main Menu... Fire Mission... Current Mission... Fire Data... Current Mission... Fire Data... Current Mission... Fire Data... Safety Data...Ö Use Terminated"

In contrast, a series of scripts generated from a usage model with a structure such as that indicated in Figure 2 would most likely not be similar to the script above. It is likely that sequences generated automatically from the usage model described above would require navigation through other parts of the usage model before 3 fire data scenarios were completed. For example, depending on the assignment of transition probabilities, a random walk through the usage model might yield a sequence such as: "Use not Invoked Main Menu... Fire Mission... Current Mission... Use Terminated, Use not Invoked Main Menu... Met... Use Terminated, Use not Invoked Main Menu... Met...., ..."

A comparison of the IMBC FQT scripts with the full IMBC usage model yielded the following information:

Each of the FQT scripts could have been generated from the usage models. With careful planning, cost-effective statistical testing could have been used for all the FQT tests.

Because the FQT scripts and the usage models were developed by different teams, one relying predominately on the SRS and one relying predominately on the specifications, the names of the screens and data values differ between the FQT and model scripts. This makes it difficult to automatically map FQT scripts onto the usage model for comparison of the Markov chain statistics.

The FQT approach minimizes the number of keystrokes required to test specific functions with specific data values.

Making an assertion about operational use based on FQT results would require that one make some assumption about whether multiple sequential executions of a particular series of screens will succeed or fail in the same way as multiple execution of the series of screens when interspersed with other uses of the software. This assumption may not be valid. The IMBC software accumulates state differently depending on the history of use of the software.

The FQT scripts tended to concentrate on one small subset of screens to demonstrate that a particular system feature executed correctly with multiple sets of data values. Less testing was done to ensure that the feature executed correctly after a significant number of missions had been run (and a significant amount of potential state accumulation.)

The FQT scripts tended to do less testing of the "cancel" arcs and other unlikely paths.

Process Tailoring to Facilitate Cost-Effective Testing

Many of the perceived barriers to application of statistical testing are in fact barriers to a rigorous testing program of any method. The IMBC testing experience demonstrated that statistical testing provides a well-defined process for test planning, test case generation, test execution, and analysis. The artifacts generated from statistical testing provided excellent documentation for the testing program and decision making process. With a small amount of training and support, even inexperienced testers quickly became effective, productive testers.

Analysis of the project yields some suggestions for process tailoring to facilitate an organization's transition from traditional testing to statistical testing. The key to successful application of statistical testing is a defined process with careful tailoring to address local issues. This was demonstrated in the IMBC project and other projects [6,2]. Particular care must be given to the following issues:

The management objectives and constraints of the certification program must be documented and well understood by management, the certification team, and the development team. These

objectives and constraints must be used to define the scope of the testing program as well as to allocate testing resources.

Certification team members must share responsibility with the requirements, specification, and development teams for review of the specification and communication about any and all assumptions.

There must be a specification of sufficient detail to provide a clear definition of correct execution of the software.

There must be traceability (including a common language) between the requirements and the specification, and the testing team must clearly understand both the functional views and the usage scenario views of the software.

Potential reuse of usage models across increments or versions of the software and application of statistical testing throughout the life cycle (including FQT) must be considered during the test-planning phase.

Multiple views of the software must be modeled and analyzed to determine an optimal test plan for each phase of the software life cycle.

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Figure 1. Most Basic Model of Software Use

Figure 2. High-level Usage Model Structure

Authors

S. Wayne Sherer is the chief scientist for the U.S. Army TACOM LCSEC located at Picatinny Arsenal, NJ. He oversees and guides software technology development and transfer into the LCSEC and directs the software acquisition and engineering process improvement efforts. Technology areas include reuse, product-lines, architecture, software support, engineering, quality, process and supporting tools. Mr. Sherer also leads policy, standards, software capability evaluation, contract monitoring and common operating environment efforts. As ARPA STARS deputy program manager (Army), he was focal point for process technology, product-line methods, and acquisition issues. He has spent over 25 years working on Army and Air Force software intensive weapon systems and is an authorized SEI Lead Evaluator.

TACOM LCSEC
U.S. Army TACOM/ARDEC
Attn: AMSTA-AR-FSF-S, Building 352
Picatinny Arsenal, NJ 07806-5000
Voice: (973) 724-3531 DSN 880-3531
Fax: (973) 724-7850/6828
E-mail: wsherer@pica.army.mil

Gwendolyn H. Walton is President of Software Engineering Technology, Inc. Dr. Walton has over 20 years of experience in all aspects of the software life cycle. She has supported a variety of customers in the application and technology transfer of software engineering methods, including U.S. government organizations, government contractors, and U.S. and international commercial firms. She has provided program management and process improvement consulting and training; has served as a project manager and lead software developer; has performed software specification, development, verification, and testing; and has done academic teaching and research in software engineering. She received a M.S. in Mathematics in 1977 and a Ph.D. in Computer Science in 1995 from the University of Tennessee.

Gwendolyn H. Walton
Software Engineering Technology, Inc.
5516 Lonas Rd, Suite 110
Knoxville, TN 37909
E-mail: Walton@toolset. com
Phone: (423) 450-5151 ext. 227
Fax: (423) 450-9110

AMC

TACOM

Practical Applications of Statistical Testing

S. Wayne Sherer
TACOM LCSEC Chief Scientist
(973) 724-3531
wsherer@pica.army.mil

Gwendolyn H. Walton
Assoc. Professor of Electrical & Computer Engr.
University of Central Florida
(407) 823-3276
gwa@ece.engr.ucf.edu

TACOM Life Cycle Software Engineering Center

Types of Service Performed

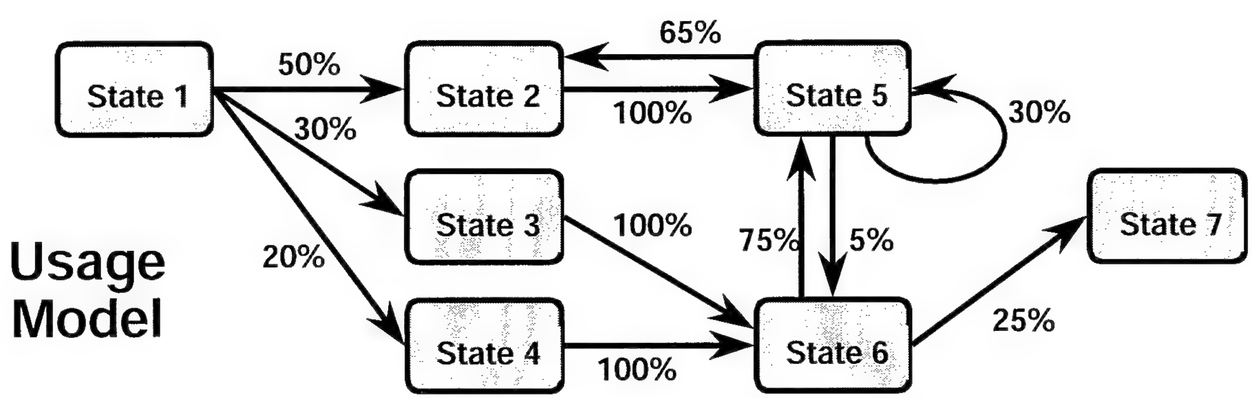
- Pre-Planning for Software Support
- Software Acquisition Support to PMs
- Manage Contracted PDSS Efforts
- Software Configuration Management
- Design and Implement Software Changes
- Computer Resource Life Cycle Management Plans

Types of Battlefield Automated Systems Supported

- Cannon and Tank Gun Systems
- Smart Mines and Munitions
- Ballistics Computers
- Gunnery Simulators and Trainers
- NBC Detection Systems

Statistical Testing

- Based upon Usage Model from which random sample of test cases are generated
  - Provides a method for deciding test budget
  - Testing performed against the product as it is to be used
  - Higher perceived quality from customer perspective
- Provides statistical basis for product reliability



Improved Mortar Ballistics Computer (IMBC)

Project Characteristics

- Next-generation system for aiming mortars in combat
- Developed using incremental life cycle
- Typical budget and schedule pressures
- Typical evolution of requirements
- Testing team had 100% turnover between increment 3 and increment 5
- Initial reluctance to rely on statistical methods to drive testing

Statistical Testing Support Provided to the Testing Team

- Formal training for team members
- Coaching on an "as needed basis"
- CASE tool support

IMBC Testing

Test Methods

- Some traditional testing and some statistical testing were performed on each increment
- Statistical methods were used to predict a field reliability of 0.93 as of increment 6
- Traditional FQT was performed after increment 7

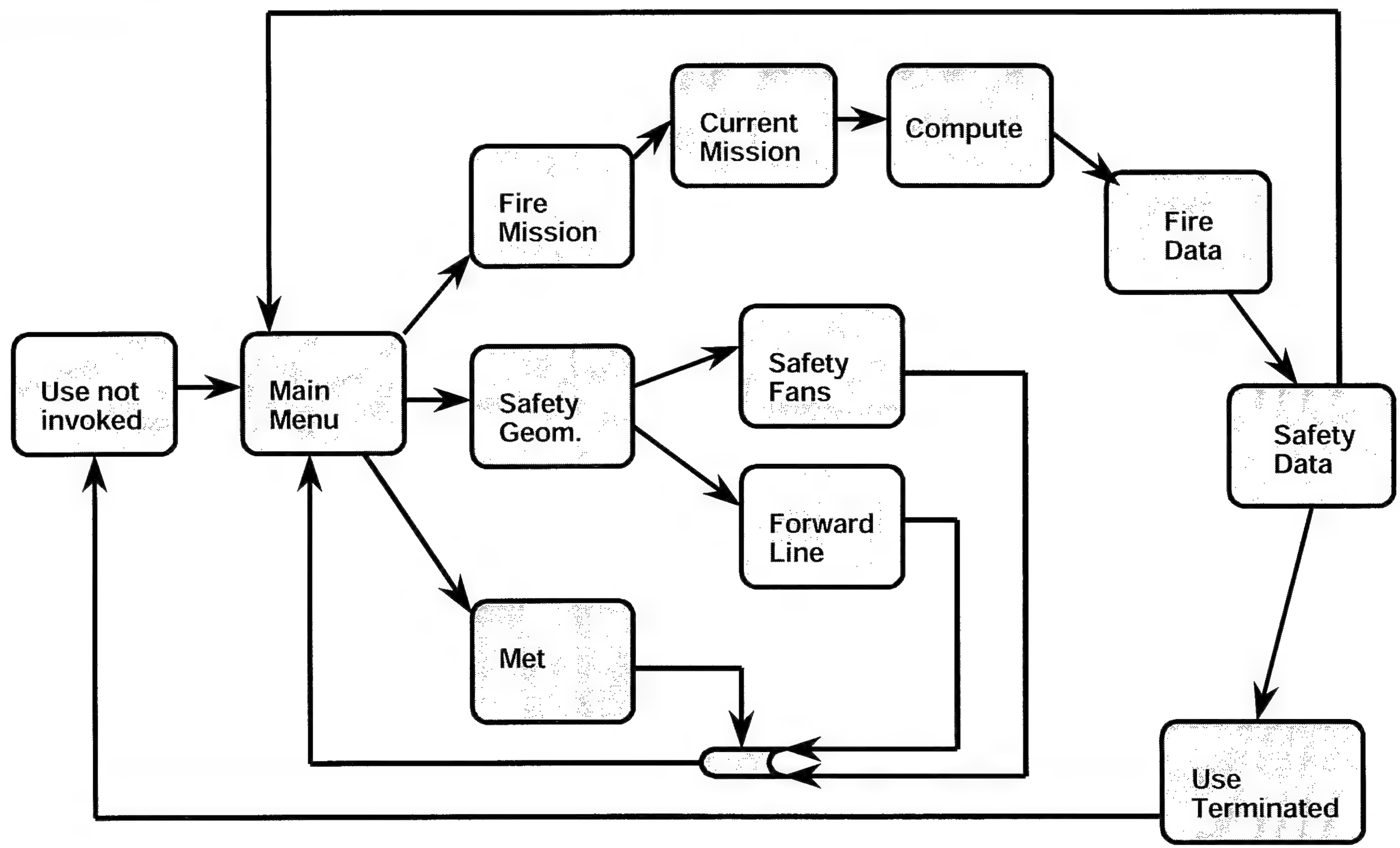
Test Boundaries

- For increments 3, 6, and 7: entire system
- For increments 4 and 5: new and modified functions
- For GOTS: interfaces only

Test Perspective

- User = soldier in the field
- Use = perform one or more missions

IMBC Testing



Process Observations

- Team members inexperienced in statistical testing were able to quickly learn the methods.
- Usage modeling helped to identify specification problems before coding was completed
- Usage models provided clear documentation of expected IMBC functionality
- The statistical testing process resulted in improved communication between test team and specification and development teams
- The test team achieved significant reuse of usage models in each subsequent increment

FQT Observations

- The FQT scripts tended to specify less testing of the "cancel input" arcs and other unlikely paths
- The FQT minimized the number of keystrokes required to execute specific functions with specific data values
- The FQT included no testing of expected long-run operational scenarios
- Each of the FQT scripts could have been generated from the usage models

General Observations

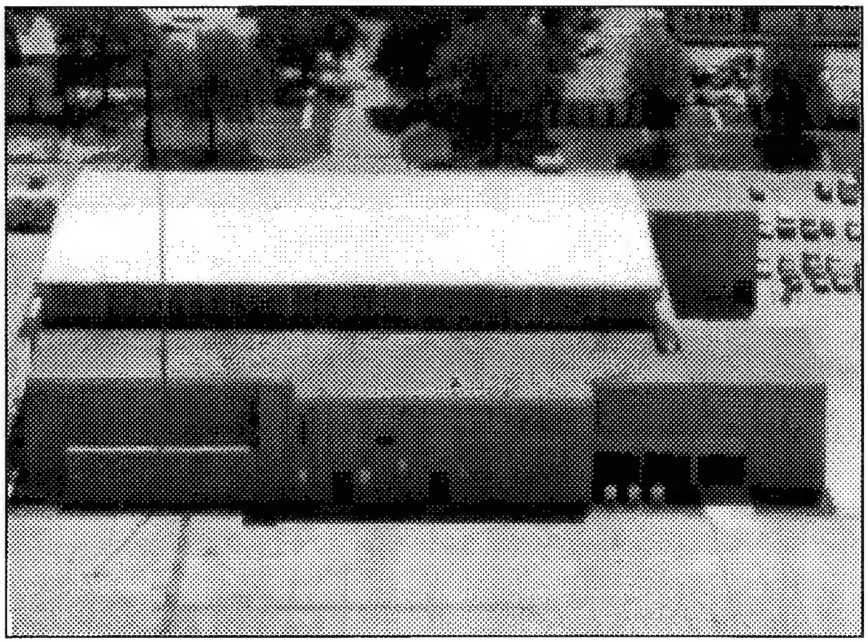
- Many of the perceived barriers to application of statistical testing are in fact barriers to a rigorous testing program of any method
- Statistical testing provided a well-defined process for test planning, test case generation, test execution, and analysis
- With a small amount of training and support, even inexperienced testers quickly became effective testers
- The artifacts generated from statistical testing provided excellent documentation for the testing program and decision making process

PREFLIGHT INTEGRATION OF MUNITIONS AND ELECTRONIC SYSTEMS

PRIMES

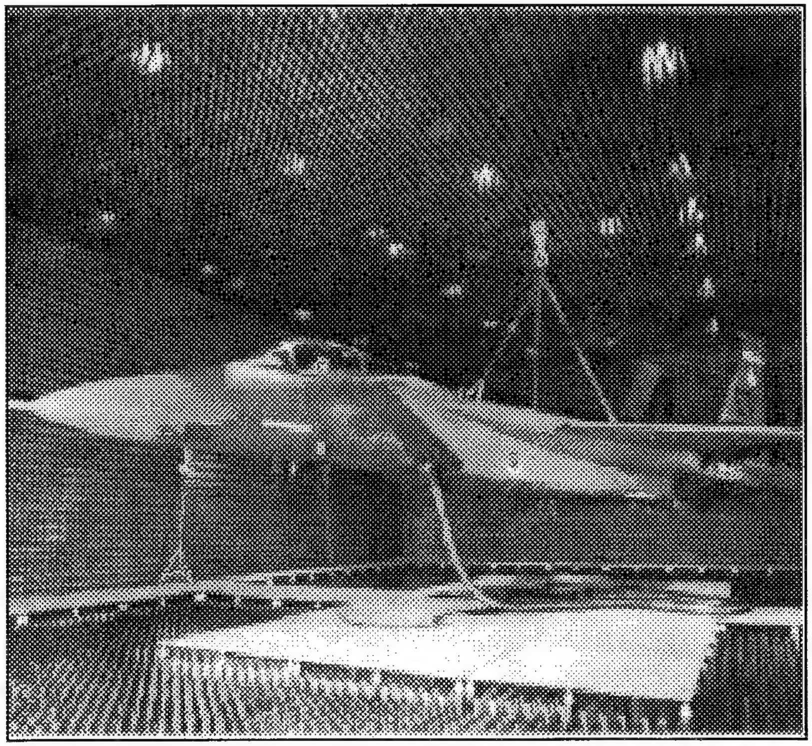
9/1/98

FACILITY CHARACTERISTICS



- MUNITIONS AND AIRCRAFT INSTALLED SYSTEMS TESTING
- LOCATED ON THE FLIGHTLINE
- FIGHTER-SIZED ANECHOIC CHAMBER
- NON-ANECHOIC HANGAR TEST AREAS
- INTEGRATION LAB TEST AREAS
- OUTDOOR RAMP TEST AREAS
- ACCREDITED BY NATIONAL VOLUNTARY LABORATORY ACCREDITATION PROGRAM

F-15 ANECHOIC CHAMBER TESTING

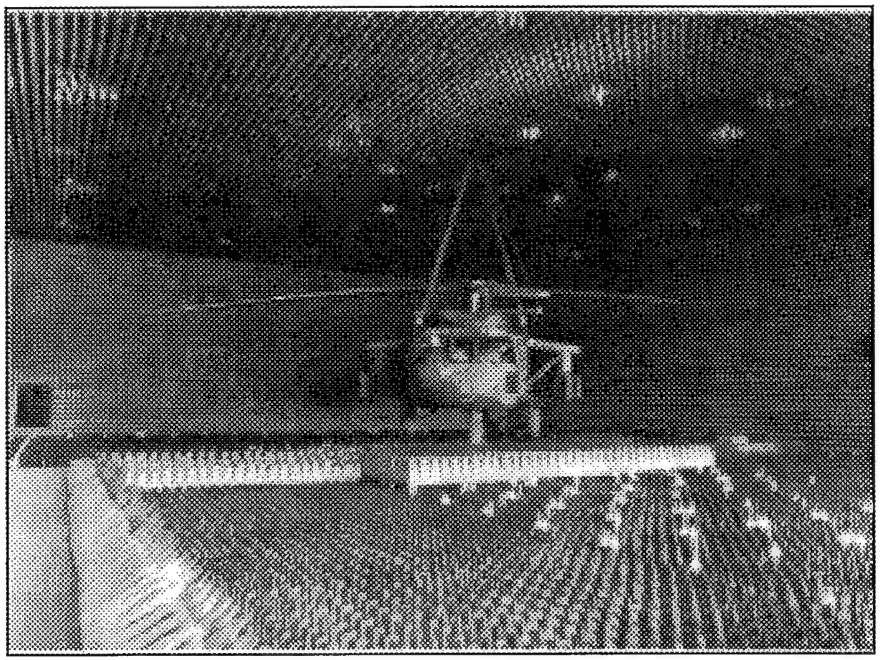


- F-15 A/B/C/D/E CAPABLE
- ELECTRICAL, HYDRAULIC, AIR CONDITIONING UTILITIES AVAILABLE
- 40 TON HOIST AND ROTATE CAPACITY
- 100 dB RF ISOLATION
- SUPPORTS MUNITIONS PERFORMANCE TESTING

F-16 ANECHOIC CHAMBER TESTING

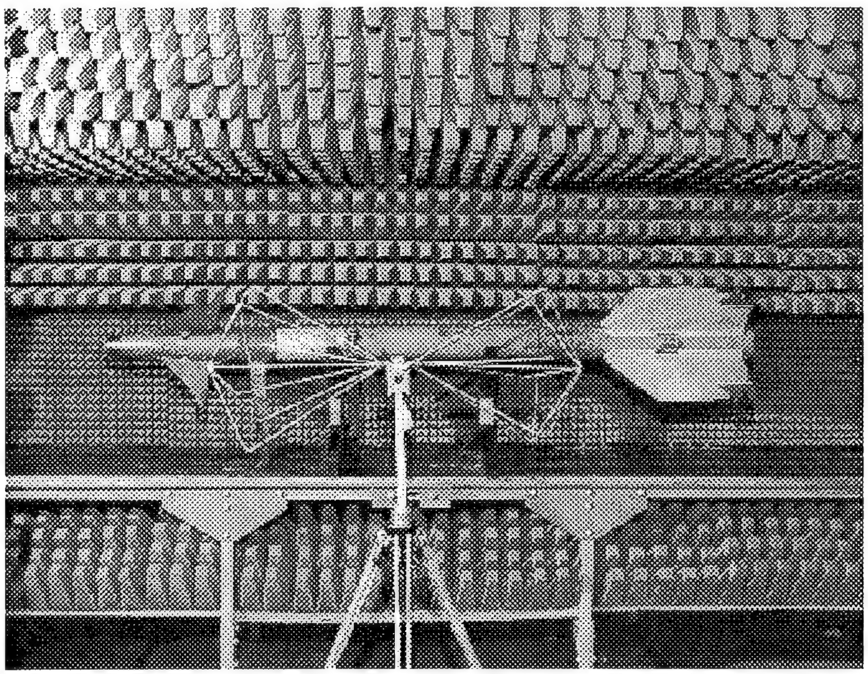
- F-16 A/B/C/D CAPABLE
- ELECTRICAL, HYDRAULIC, AIR CONDITIONING UTILITIES AVAILABLE
- 40 TON HOIST AND ROTATE CAPACITY
- 100 dB RF ISOLATION
- SUPPORTS ELECTRONICS SYSTEMS TESTING

HELICOPTER TESTING



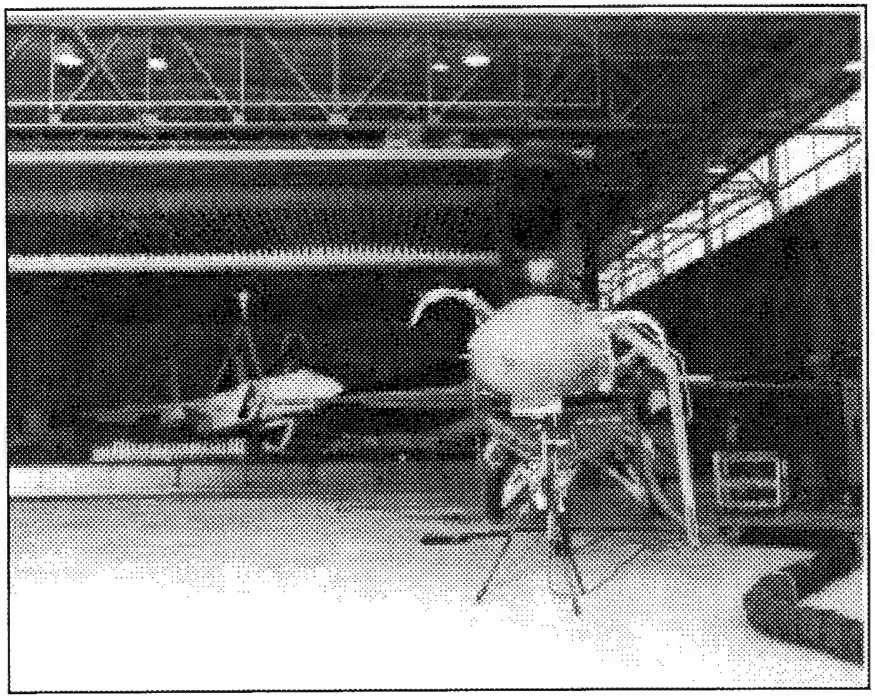
- MH-53J, UH-60, UH-IN, AND AH-64 CAPABLE
- SUPPORTS US ARMY AVIATION TEST PROGRAMS
- ELECTRONIC SYSTEMS PERFORMANCE TESTING
- EMI QUALIFICATION TESTING

EMI/EMC LABORATORY



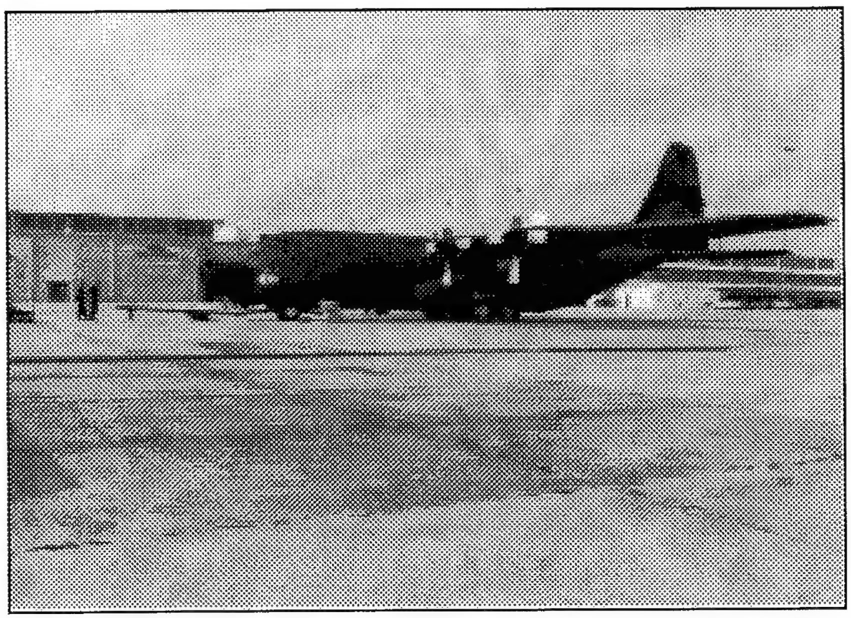
- NVLAP ACCREDIATION THROUGH NIST
- NARTE CERTIFIED EMC ENGINEER
- RADIATED/CONDUCTED EMISSIONS
- RADIATED/CONDUCTED SUSCEPTIBILITY
- MIL-STD-461 AND 462, PLUS MANY OTHER SPECIFICATIONS

PRIMES HANGAR FLOOR TEST AREA



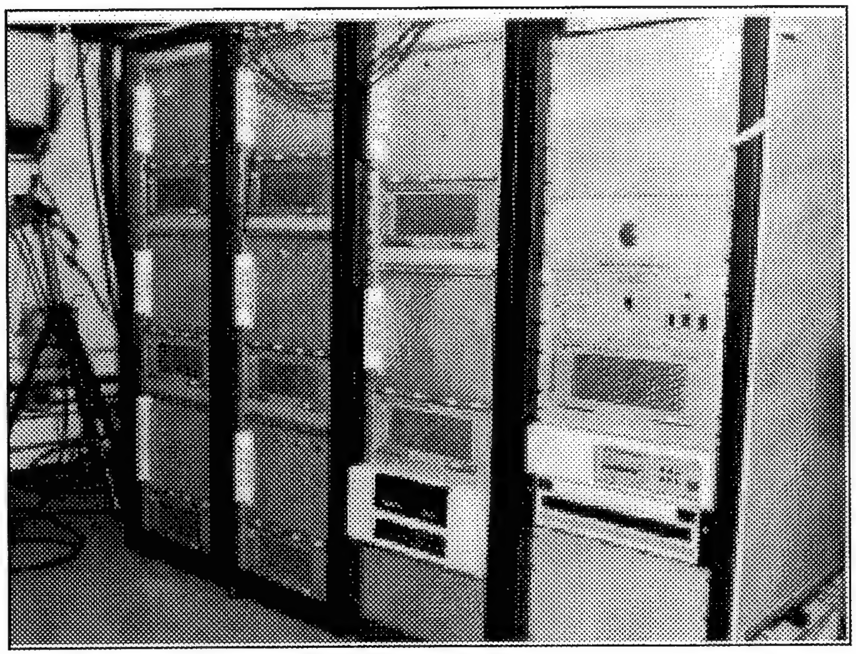
- NON-ANECHOIC TEST AREA
- ANTENNA HATS USED TO COUPLE RF SIGNALS
- PRE AND POST FLIGHT TEST AREA
- NO FUEL PURGE REQUIRED
- ACCESS TO ALL FACILITY SIMULATION AND INSTRUMENTATION CAPABILITIES

LARGE AIRCRAFT RAMP TESTING



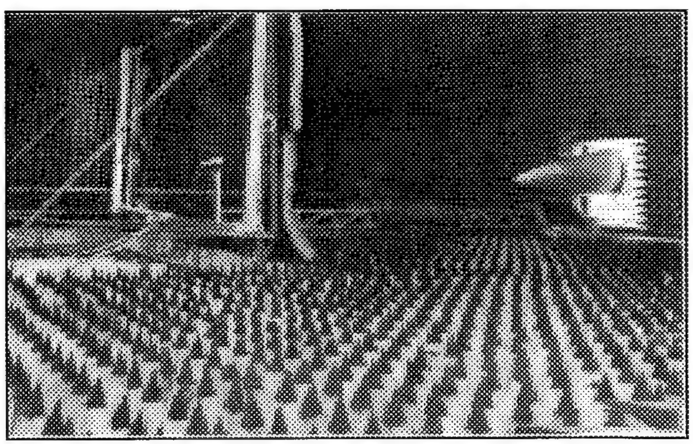
- OUTDOOR TEST AREA
- RADIATED TESTING AVAILABLE
- ACCESS TO ALL FACILITY SIMULATION AND INSTRUMENTATION CAPABILITIES

ADVANCED MICROWAVE ENVIRONMENT GENERATOR



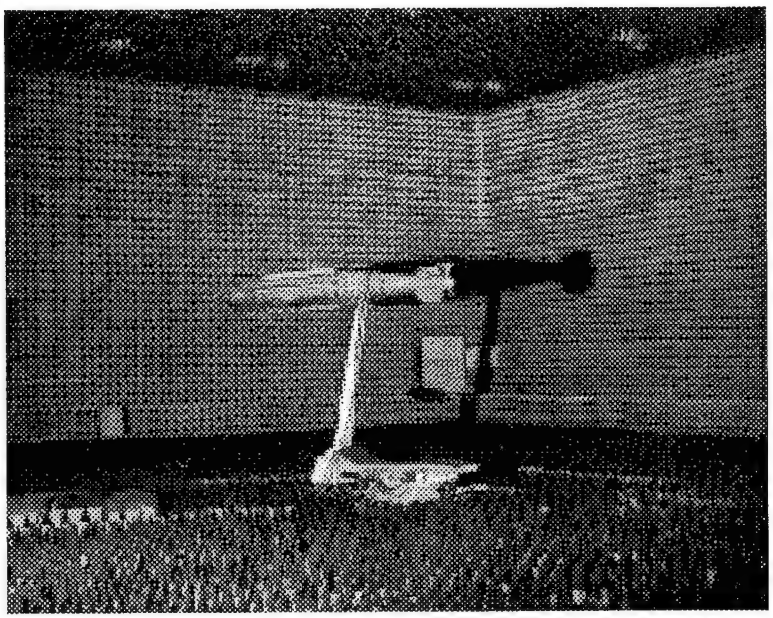
- AIRBORNE INTERCEPTOR EMITTER SIMULATION
- GROUND THREAT EMITTER SIMULATION
- DYNAMIC ANGLE-OF-ARRIVAL
- LOW, MEDIUM, AND HIGH PRF
- VALIDATED BY NATIONAL AIR INTELLIGENCE CENTER

TARGET AND ECM GENERATION SYSTEM (TEGS)



- FOUR TARGET, FULL MOTION RADAR TARGET SIMULATION
- FULL FEATURE ECM SIMULATION
- DYNAMIC RCS AND JEM SIGNATURES
- GROUND CLUTTER SIMULATION

GPS SIMULATION

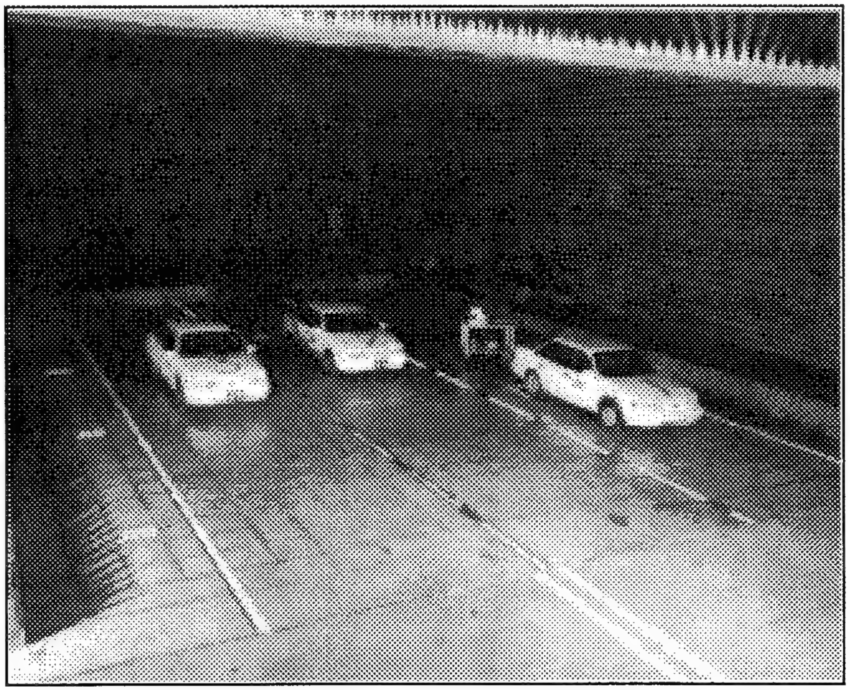


- L1 AND L2 FREQUENCIES
- C/A AND P CODES
- ANTI-JAM TESTING
- ANTI-SPOOFING
- SELECTIVE AVAILABILITY (S/A)
- DIFFERENTIAL GPS TESTING
- 10 RF CHANNELS

PRIMES TEST CONTROL STATION

- CONTROL AND MONITOR DYNAMIC SIMULATIONS
- REAL-TIME DATA ANALYSIS
- DISTRIBUTED INTERACTIVE SIMULATION NODE
- SUPPORTS AIR-TO-AIR AND AIR-TO-SURFACE WEAPON TESTING

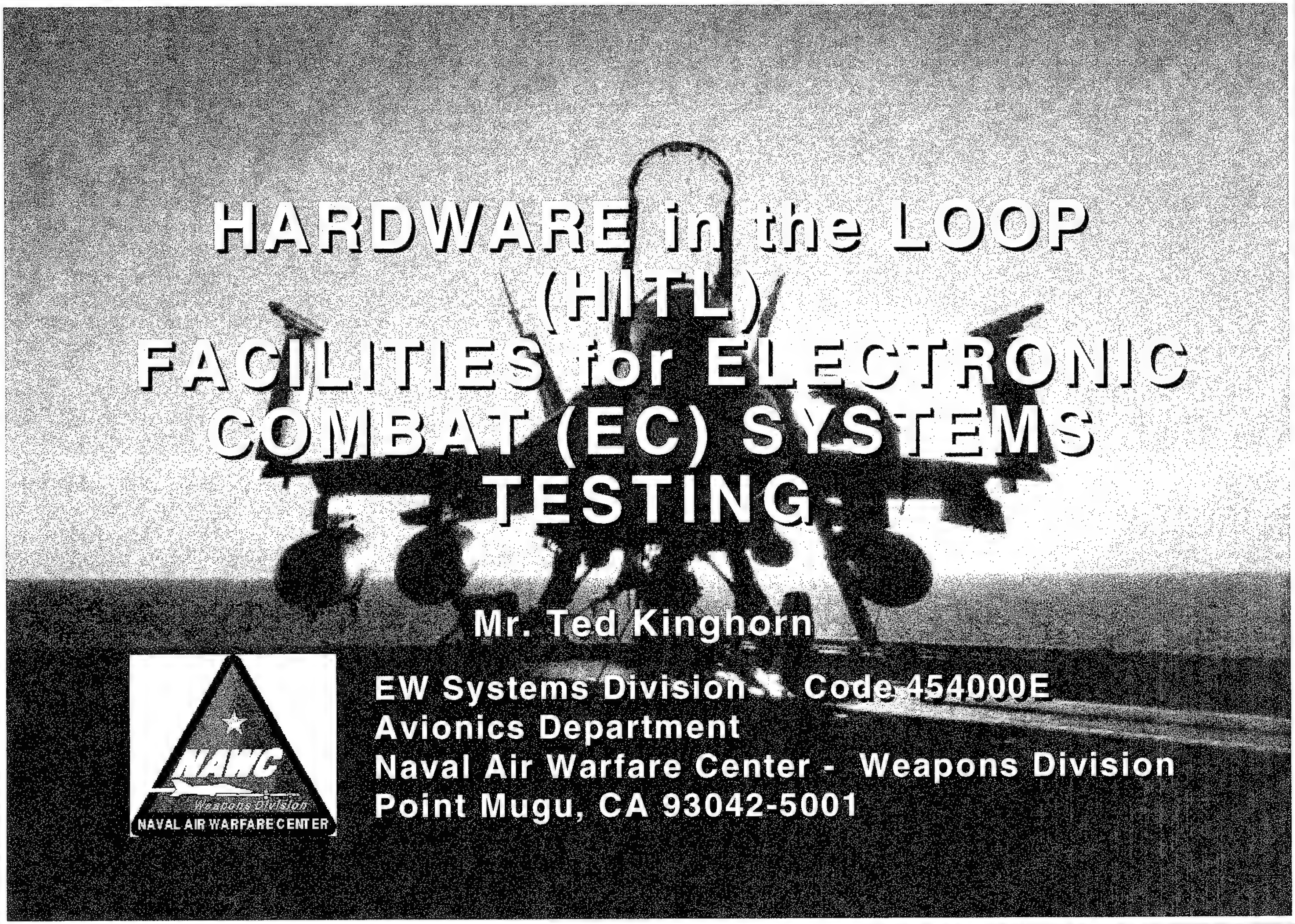
COMMERCIAL TESTING



- SUPPORTS AUTOMOBILE DEVELOPMENT PROGRAMS
- CERTIFIED EMI LABORATORY FOR ELECTRONICS SYSTEMS TESTING
- COMPETITIVE INDUSTRY COST RATES
- MEDICAL EQUIPMENT AND SYSTEMS TESTING

Measurement Capabilities

- Weapon System Performance
  - Mil Std 1760 Umbilical
  - Pre- and Post-launch Integration
  - Munition & Aircraft Counter-countermeasures
- Electromagnetic Interference and Capability
  - Mil Std 461/462 Qualification Testing
  - Mil Std 1818 System Testing
- Antenna Pattern Mapping

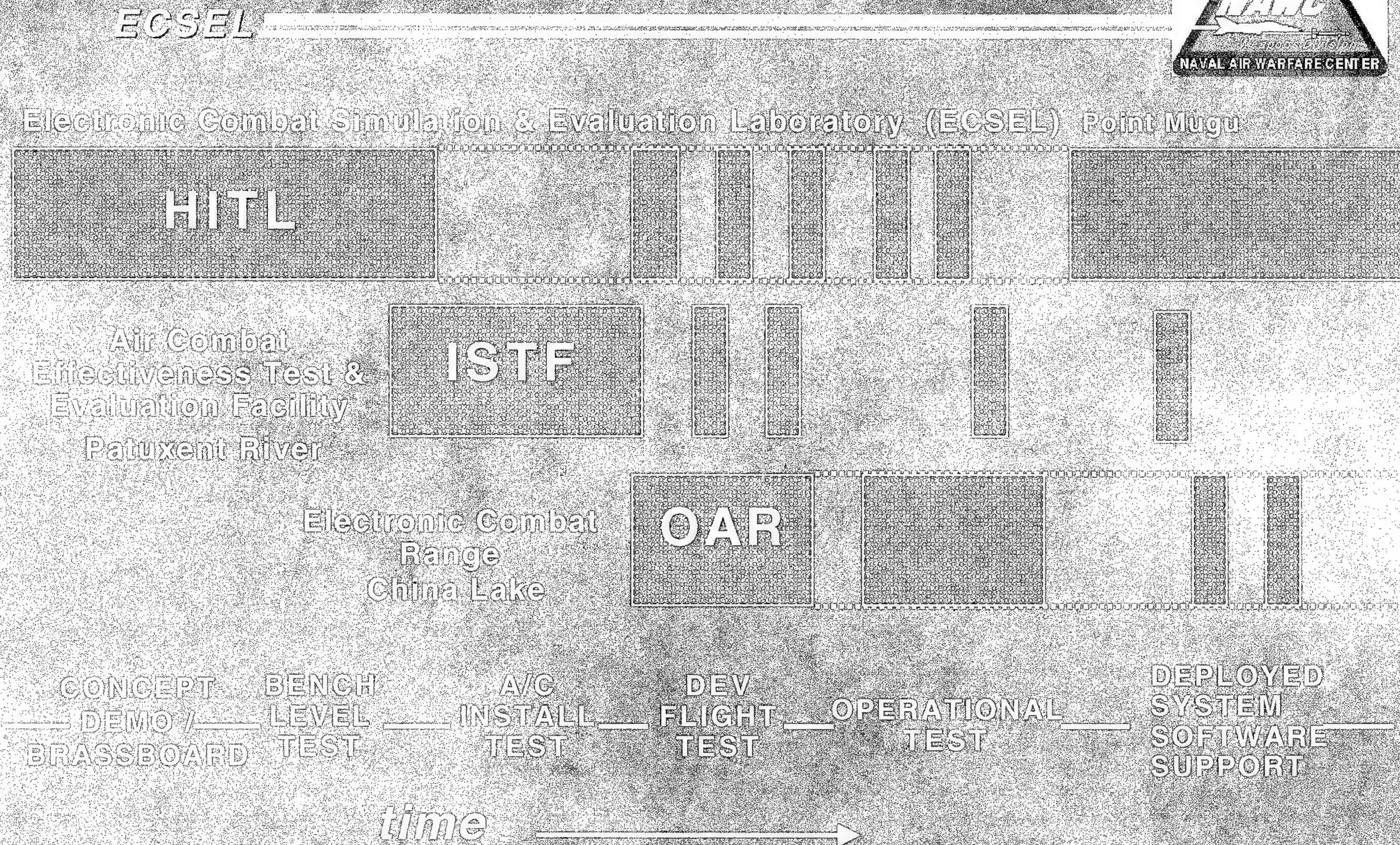


HARDWARE in the LOOP (HITL) FACILITIES for ELECTRONIC COMBAT (EC) SYSTEMS TESTING

Mr. Ted Kinghorn

EW Systems Division - Code 454000E
Avionics Department
Naval Air Warfare Center - Weapons Division
Point Mugu, CA 93042-5001

TEST PROCESS



HITL FEATURES

ECSEL

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- EC Software and Hardware as a system
- Focus - EC system vs. Threat
- Control of test conditions
  - Programmability, Repeatability
- Maximum instrumentation capability
  - Internal access to System-Under-Test
- Signal density
- Security
- Scheduling / availability
- Cost of Operations

UNCLASSIFIED

RELATIVE TEST COST

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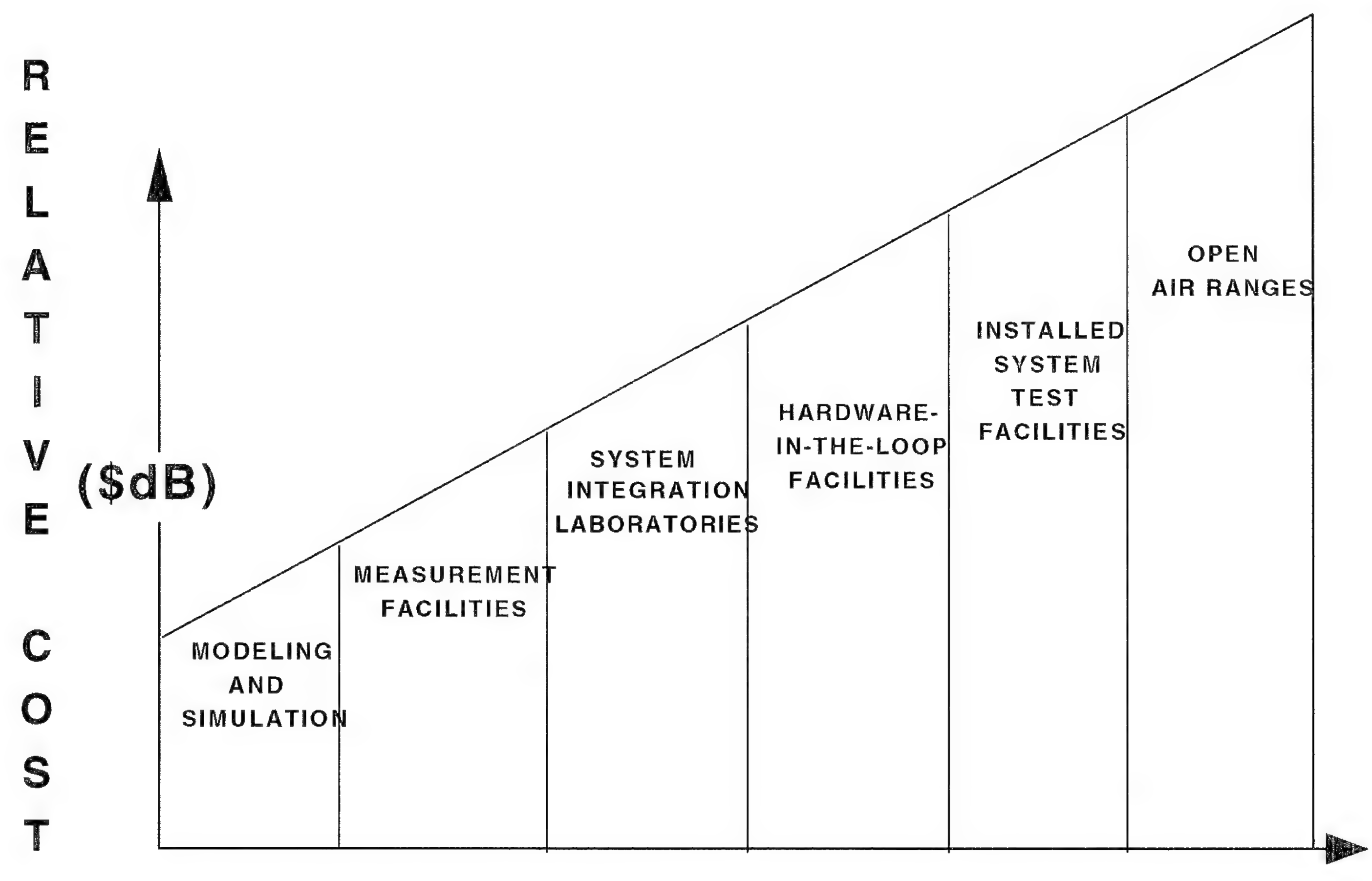

UNCLASSIFIED

EC HITL IMPLEMENTATION

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- Simulate the EC system's "environment"
  - Combat conditions, scenarios
  - Very high fidelity threat simulators
    - Real threat hardware where possible
  - Aircraft (ownship) interfaces and performance characteristics
    - Blanking, mission computer, weapons, etc.
    - Antenna patterns & Radar cross-section
    - Aerodynamics & flight profiles
- Instrument the System-Under-Test
  - Observe detailed responses to the environment
- Instrument the threat systems
  - Observe effects of EC responses (Jamming) on the threat

EC HARDWARE IN THE LOOP

ALQ-165 Advanced Self Protection Jammer (ASPJ)

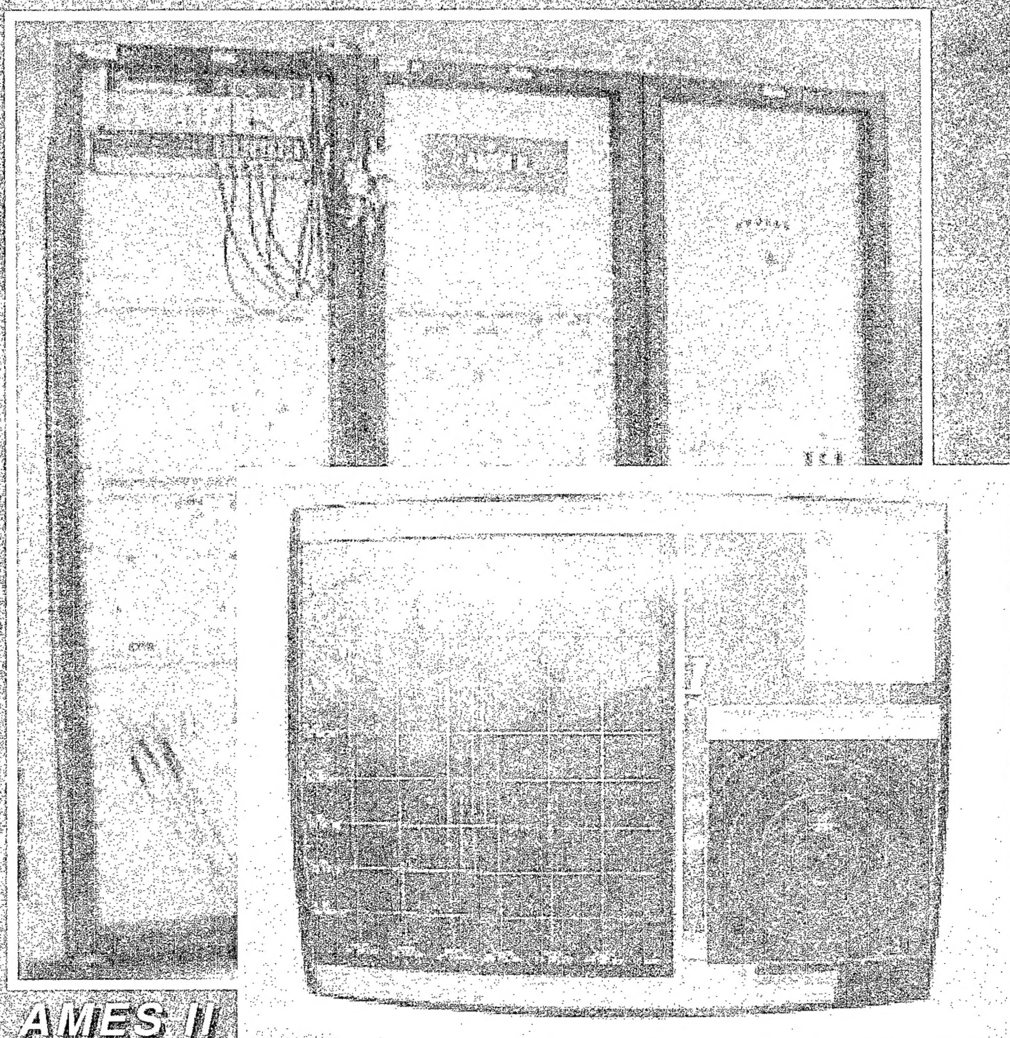
THREAT HARDWARE

- Threat Radar Systems
  - Simulators
  - Actual Hardware
- Missile Seekers
- Weapon System Operators
- Weapon "Fly-Out" Models

I-HAWK (Export) Missile Seeker
ECSEL Anechoic Chamber

EC MISSION SIMULATION

ECSEL



AMES II

- Electronic Combat Range (ECR)
- Other EW Ranges
- Customer Specified
- Stress Test
- Mission Planning System Interface

SUMMARY
Hardware in the Loop

- Lowest cost test of actual EC hardware/software system against realistic threat.
- Permits testing prior to platform availability.
- Controlled test environment for isolation of problems.
- Maximize readiness, minimize waste in ISTF and OAR test phases.

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For further information contact:
Mr. Harry Banks
Head, Countermeasures Branch
Code 454300E
(805) 989-3400 DSN 351-3400 Fax (805) 989-3408
Mr. Brad Coler
Code 454320E
(805) 989-3400 DSN 351-3400 Fax (805) 989-3408
EW Systems Division
Avionics Department
Naval Air Warfare Center - Weapons Division
Point Mugu, CA 93042-5001